U. S. DEPARTMENT OF AGRICULTURE,

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GIFFORD PINCHOT, Forester.

EFFECT OF MOISTURE UPON THE STRENGTH AND STIFFNESS OF WOOD.

BY

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Forest Service,
Washington, D. C., December 16, 1905.

Sir: I have the honor to transmit herewith a manuscript entitled "Effect of Moisture upon the Strength and Stiffness of Wood," by Harry Donald Tiemann, Assistant Forest Inspector in the Forest Service, and to recommend its publication as Bulletin 70 of the Forest Service.

The tests from which these conclusions are drawn were conducted in cooperation with the Yale Forest School.

The 4 plates and 25 text figures accompanying the manuscript are necessary for its proper illustration.

Respectfully,

Gifford Pinchot, *Forester.*

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

The investigations of the mechanical properties of wood by the Forest Service are being carried out by several timber-testing stations, in cooperation with the University of California, Purdue University, the University of Oregon, the University of Washington, and the Yale Forest School.

The general aim of these tests is not only to supply useful information for engineers and architects, but also to determine the useful qualities and values for specific purposes of quick-growing woods, thus promoting the practice of conservative forest management, and to determine proper substitutes for material which is more valuable for uses other than those for which it is now employed.

The programme of the work, as planned at the present time, is as follows:

TESTS TO DETERMINE PROPERTIES OF STRUCTURAL TIMBER.

Series I.—Tests of the mechanical and physical properties of timber in forms found on the market, the material to be of actual sizes and grades of commercial products. The purpose is to determine moduli for design; to determine the value of woods now considered inferior; to determine the liability to knots, and the corresponding reducing factors; to arrange a table of standard weights, and rules of inspection and grading; and partly to compare the properties of species from different regions.

TESTS TO DETERMINE THE EFFECT OF VARIATIONS IN THE TESTING PROCESS.

Series II.—Effect of rate of application of load, including impact tests.
Series III.—Effect of moisture.

STUDIES OF THE EFFECT OF TECHNOLOGICAL PROCESSES.

Series IV.—Preservatives.
Series V.—Methods of seasoning.
Series VI.—Fire retardants.

Such investigations in the field of utilization of wood necessarily include tests to determine the various mechanical properties of wood, in the shape both of small pieces and of actual manufactured products. Such tests may be accompanied by a critical scientific study of the methods of test, and a determination of the effect of various factors which enter into the conditions under which the tests are made, as, for instance, speed of loading and moisture.

The determination of the effect of the latter factor was assigned to the technological laboratory of the Yale Forest School, under the general direction of Prof. J. W. Toumey. After the main plan of procedure had been laid down, the work was assigned to Mr. H. D. Tiemann, testing engineer at the laboratory, whose report forms the main subject-matter of this bulletin. Briefly stated, Mr. Tiemann has once for all determined the factors by the use of which the results of tests at different degrees of moisture may be reduced to a common basis in the case of certain species and certain kinds of tests. He has established the per cent of moisture at which the cell walls are saturated in the case of these species, and has determined the true nature of the law representing the effect of any further reduction of moisture on the strength of timber. His studies explain the reasons for the various facts. His subsidiary studies on casehardening, on prolonged soaking, and on soaking followed by drying have direct application to the technology of various products and will be of great value to students and engineers.

These results apply to hardwood material in small forms, such as carriage stock, etc., and softwood timber in some forms, such as cross-arms for telegraph poles, where thorough and uniform drying and consequent large increase in the strength may be obtained.

Incidental results bearing on this same problem, which have been secured from tests in the other timber-testing stations of the Forest Service, are given in the Appendix of this bulletin.

W. K. Hatt,
Civil Engineer, Forest Service.

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EFFECT OF MOISTURE UPON THE STRENGTH AND STIFFNESS OF WOOD.

PURPOSE OF THE STUDY AND ITS RESULTS.

Many factors and conditions affect the strength of wood. The strength of a wooden block of a given species depends not only upon its relative freedom from imperfections, such as knots, crookedness of grain, decay, wormholes, or ring shakes, but also upon its density, upon the rate at which it grew, and upon the arrangement of the various elements which compose it. For a piece of wood is like an artificial structure, which owes its strength not only to the material from which it is made but also to the shape and arrangement of its framework.

The factors and conditions which affect the strength of wood are of two classes: (1) Those which are inherent in the wood itself, and which may cause differences to exist between two pieces from the same species of wood or even between the two ends of the same piece of lumber, and (2) those which are extrinsic to the wood, such as moisture, oils, and heat. The extrinsic conditions in any given block may be of a temporary character, but the inherent factors of that block are permanent qualities. Moisture has more effect on the strength of wood than any other extrinsic condition. Though this effect is generally temporary, it is far more important than is commonly realized. As the moisture of a piece of wood is reduced by drying, the strength of the wood increases, and as moisture is reabsorbed the strength, up to a certain limit, is again reduced. So great, indeed, is the effect of moisture that under ordinary conditions it outweighs all the other causes which affect strength, with the exception, perhaps, of decided imperfections in the wood. The desirability of measuring and defining this effect is therefore obvious.

Wood is composed of organic products. The chief material of its make-up—that which forms the walls of the minute cells and

which gives to the wood its form and structure—is cellulose. This material in its natural state in the living plant or green wood contains intimately imbibed within its substance a large amount of moisture[a] (from 25 to 30 per cent of its weight), which it readily parts with upon being dried in the air or artificially by heat. The effect of the moisture within the cellulose substance is to render it more or less pliable, and the more water it contains the more pliable it becomes. Familiar examples of the same effect are afforded by the softening action of water upon gelatin, glue, a sheet of paper, or a piece of cloth. The same law applies also to wood substance and consequently to large timbers and wooden structures. What the physical action of the water is upon the molecular structure of organic material to render it softer and more pliable, is largely a matter of conjecture and need not be discussed here in greater detail.

In order to arrive at the fundamental law governing the relation of moisture to the strength of wood, it is necessary to eliminate as far as possible all other variable factors. To this end the test pieces must be of uniform quality and of suitable size, and their moisture content accurately determined in each case.

Many related problems must necessarily be taken into account, such as the effect of volatile oil upon the strength and upon the moisture determinations, the effect of drying and resoaking, and like influences.

For this study longleaf pine (*Pinus palustris*) and red spruce (*Picea rubens*) were taken as representative coniferous woods, on account of their large use for structural purposes, and chestnut (*Castanea dentata*) was taken as representative of the ring-porous woods. Tests were made for ultimate strength and stiffness in compression parallel to grain and in bending of beams, and also for shearing and compression at right angles to grain. Of these tests those of compression parallel to grain yielded the most regular results and, for the purpose in view, by far the most important ones, while compression at right angles to grain proved the least satisfactory. For compression parallel to grain, the test specimens were all cut 2 by 2 inches in cross section and 5¾ inches in length. The beams, loaded at the center, were 2 by 2 inches cross section and 40 to 42 inches long, having a clear span of 36 inches. In the shearing tests the shearing area was 2 by 2 inches in single shear.

The results show that drying produces a remarkable increase of strength in the wood. When artificially dried until only about 3½ per cent of the moisture remains it is several times stronger than in the green or in the water-soaked condition. How many times the

[a] See theory of the fiber-saturation point, p. 82.

strength is multiplied in drying to this degree in the case of each of the following species is thus expressed in figures:

Species.	In compression parallel to grain.	In bending.
Longleaf pine	2.9	2.5+
Spruce	3.7	2.8
Chestnut	2.8	2.1
Loblolly pine heartwood	3.0	....
Red fir	2.6	....

For a still drier state these ratios are even greater, in the case of spruce compression being as high as 4 for a condition of 1 per cent of moisture. In other words, a completely dry spruce block 1 inch square will hold up a dead load 4 times as great as that which a green block of the same size will support.

In large sticks the moisture is apt to be unequally distributed, the surface being drier than the interior, so that not so high a degree of drying is attained in the seasoning process. Furthermore, the process of partially seasoning these large sticks induces season checks or ring shakes, which weaken the timber. The development of these defects depends on the species of the wood and the part of the tree from which the large stick is sawed. The design of structures should be based on unit stresses which have been derived from actual tests of large sticks in the condition in which they are to be used. Results of tests on small dried sticks do not apply.

It must be noted, however, that the ratios given above apply only to wood in a much drier state than usually occurs in practice. For wood in an air-dry condition, containing 12 per cent of moisture, these ratios are but little over half as great. They are:

Species.	In compression parallel to grain.	In bending.
Longleaf pine	1.7	1.5
Spruce	2.4	1.9
Chestnut	1.8	1.6
Loblolly pine heartwood	2.0	....
Red fir	1.7	....

The stiffness (within the elastic limit) follows a similar law, but does not increase quite so rapidly. The ratios of the stiffness of green wood to that air dried to 12 per cent moisture and to that kiln dried to 3½ per cent are:

	In compression parallel to grain.		In bending.	
	Kiln dry.	Air dry.	Kiln dry.	Air dry.
Longleaf pine	1.6	1.2	1.6	1.1
Spruce	2.3	1.6	1.4	1.2
Chestnut	1.4	1.2	1.4	1.2
Loblolly pine heartwood	1.9	1.4	....	....
Red fir	1.5	1.3	....	....

The elastic limit increases similarly with the strength, the ratios being:

	In compression parallel to grain.		In bending.	
	Kiln dry.	Air dry.	Kiln dry.	Air dry.
Longleaf pine	2.6	1.7	2.9	1.6
Spruce	3.8	2.7	2.9	1.9
Chestnut	2.4	1.5	2.3	1.6
Loblolly pine heartwood	2.8	1.8	....	....
Red fir	2.3	1.6	....	....

On the other hand, the shearing strength parallel to grain, or resistance to forces tending to overcome the cohesion of the fibers along the direction of their length, is a very variable quantity, and although it may increase with the dryness in a similar manner it can not always be depended upon to do so. The cause for this is not wholly apparent, but it seems very probable that internal stresses during the drying may cause small, invisible checks or separations of the fibers, thus reducing the shearing strength. Whether the shearing plane is tangential or radial to the rings makes very little difference.

Soaking in cold water does not diminish the strength of wood beyond a certain limit, which is the point at which the substance of the wood becomes saturated. Beyond this point the water merely enters the pores of the wood without any further weakening effect. Fresh or green wood is in this saturated state, and consequently in its weakest condition at the temperature considered, so that soaking at this temperature does not reduce its strength. Heating the water, however, greatly reduces the strength, since the saturation point is thus moved farther down the curve, as will be explained later, on page 84.

Though drying temporarily increases the strength, it has also an inherent weakening effect, so that a block which has been dried and then remoistened is weaker than one of an equal degree of moisture which has not been dried. This weakening effect appears to vary with the process used in drying, being most marked in the case of steaming at high pressures.[a] Hence the advantage of slow drying at low heat, and the harmful effect of forcing the process by steaming under pressure.

PLAN OF THE INVESTIGATION.

The general plan for the present study of the relation of moisture to strength was outlined by Dr. W. K. Hatt, civil engineer of the Forest Service, in a circular which appeared July 1, 1903, and was further described in the proceedings of the American Society for Testing Materials, Volume III, 1903. This plan was followed, in the main, with such alterations and additions as experience indicated. The actual procedure was as follows:

For each kind of test a series of blocks of the wood as nearly as possible identical in structure was selected. Each block of the series was reduced to a different moisture content and then tested. (See fig. 1, Pl. I.) With the exception of some of the beam series of the longleaf pine, each series of blocks was cut from the same plank, as will be explained further on. The moisture content was subsequently determined by drying out a thin disk cut from the region of rupture. As the moisture question is the basis of the investigation, it is discussed in considerable detail on page 65. The moisture conditions at which tests were made with the blocks of each series were, in general, these:[b]

Block No. 1. Water soaked.
2. Fresh green.
3. Dried to about 20 per cent moisture.
4. Dried to about 15 per cent moisture.
5. Dried to about 10 per cent moisture.
6. Kiln dry.
7. Kiln dried and allowed to reabsorb 15 per cent.
8. Kiln dried and resoaked.

A number of these series—from five to sixteen—were tested in each case, and separate curves were drawn for each individual series. This gave a more reliable average and at the same time

[a] This laboratory is at the present making a thorough study of the effect upon the strength of wood of the various processes of drying.

[b] For convenience of reference the term "series" will be used in the following pages to designate all the tests of one kind, through all the moisture degrees, made on pieces prepared from the same stick; and the term "set" will apply to all tests of one kind and one species made at the same moisture degree, comprised of one test from each of the several series.

indicated the influence of the inherent qualities of each, which are chiefly density, rate of growth, and content of resinous materials.

As a check, an additional block was sometimes cut at the end of a series and compared with the first block, in order to determine whether the wood was the same at the two ends of the stick from which the blocks of the series were cut.

The kiln-dried blocks which were allowed to reabsorb moisture showed, when compared with the drying curve, the loss of strength which they had sustained in the drying process.

The work was begun in the summer of 1903, but a fire in the winter destroyed many of the records and greatly delayed the work.

During this time experience indicated various improvements and changes in the methods, and it was found also that the different species required very different treatment. For these reasons it will be best, after giving a general description of the methods, to examine each species in order, to describe its special treatment, and to note wherein any differences occurred.

KINDS OF TESTS.

The main tests were as follows:

(1) Compression parallel to grain.

(2) Bending.

(3) Shearing: (*a*) Tangential; (*b*) Radial.

(4) Compression at right angles to grain: (*a*) Tangential to the rings; (*b*) Radial to the rings.

The last kind of test, however, was not carried out with every series. For the longleaf pine, 7 series each of Nos. 1, 2, and 3, and 6 series of No. 4 were tested, making about 200 tests in all. The last mentioned, however, No. 4, were rendered valueless through the loss of moisture records by fire. For the spruce there were 16 series of No. 1, 12 of No. 2, 16 of No. 3, and 5 of No. 4, making 447 tests in all. For the chestnut there were 10 series of No. 1, 10 of No. 2, and 10 of No. 3, making 214 tests in all.[a]

In order to carry on the work intelligently it was necessary to solve many related problems, among which may be mentioned especially: The exact point where the strength first begins to increase during the process of drying the green or wet wood, or the "fiber-saturation point," as it is herein designated; the effect of temperature upon this point; the effect of steaming and boiling; the effect of time in soaking; the effect of "casehardening" in drying. Over 600 special tests were

[a] In addition to the mechanical tests and moisture determinations, volatile oil determinations were made upon a number of the longleaf pine blocks, a discussion of which is given on page 127. The amount was found to be so small that these tests, which required a great amount of time, were discontinued when the other species were taken up.

made for these side problems. Microscopic study of the manner in which the rupture takes place and of the distribution of the moisture and resins in the process of treatment was also necessary, as well as a number of other experiments not here enumerated. Altogether over 1,600 mechanical tests are embraced in this report, besides nearly three times as many moisture determinations.

METHODS OF PROCEDURE.

THE TEST MATERIAL.

In order to establish the fundamental law of the relation of moisture to the strength of wood, it is necessary to eliminate all other variable quantities as far as possible from the tests. For this reason the specimens must be free from defects, of straight, normal grain, and of uniform rate of growth. These variable conditions may subsequently be taken into consideration, after the law in question has first been determined. For example, having found the law which applies to perfect wood, proper deduction must be made when this law is applied to timbers having defects, the deduction being proportional to the influence of such defects, as determined by other experiments.

The source of the lumber is immaterial, provided it be of the desired quality and in the same condition as when freshly cut. For this reason a detailed account of the conditions of growth is not here recorded, mention being made, when describing the several species, merely of the region and of the probable time of cutting.

The lumber from which the tests were made was obtained from the market, in selected 3 or 4 inch planks, and in the freshest green condition obtainable. The longleaf pine had been kept in the water at New Haven in large sizes, and was sawed into planks when ordered. The spruce was a fresh cargo from Maine and was secured as soon as unloaded. The chestnut was freshly sawed from the log at a mill near New Haven.

The planks were cut into sticks and the latter planed to exact 2 by 2 inch size. Each stick was so lettered that its position in the plank was indicated. With the spruce and chestnut the planks were sawed into 3½-foot lengths before cutting into sticks, which made a convenient size to handle for all purposes, care being taken in cutting the sticks to select them to the best advantage for the series of tests in view. These sticks were then cut into the test specimens and each one lettered so as to indicate the stick from which cut. Then all specimens were weighed and subjected to whatever treatment was required, one set being tested at once, or kept in a damp box until tested, and the rest dried or soaked, as the case might be.

RECORDING DATA.

The test data were taken upon printed forms prepared for the purpose. In general, the following data were recorded: Weight when first cut, weight at test, rings per inch, dimensions, time of starting test, time near elastic limit, time of completion of test, deflections and loads at stated intervals up to and beyond the maximum point. The weights of the various moisture disks and any circumstances of special note connected with the tests were also recorded, and small diagrams were made showing how the failure occurred.

From these data the various coefficients and factors were calculated and the curves were drawn, as explained on page 70.

MACHINES AND EQUIPMENT.

The laboratory at the Yale Forest School is equipped with all desirable tools and wood-working machinery, as well as with testing machines and apparatus, so that all the operations, including the preparation of the test specimens, were conducted on the spot. Most of the tests were performed upon a 30,000-pound Olsen testing machine, such as is commonly used for metal tests. Some of the dry specimens, however, exceeded the capacity of this machine and were tested upon a 150,000-pound Riehlé testing machine. The power for operating all the machinery was furnished by a gas engine. The testing machines were accurately calibrated by a pair of calibrating levers with standard weights made expressly for this purpose. It will suffice here to state that the variations which occurred in calibration were within reasonable limits.

Other apparatus will be more fully described when considering the various tests for which it was used.

TREATING THE SPECIMENS BEFORE TESTING.

The object in view was to dry each specimen to its proper moisture content, so as to obtain as nearly uniform moisture distribution as possible, and not to injure the piece in any way by causing stresses or checks. This required a great deal of careful manipulation. As the block necessarily dries from the outside inward, it is evident that, except in the wet or green condition and in the perfectly dry condition, the piece is apt to be damper in the middle than on the surface. It was found to be a very difficult problem to obtain correctly the intermediate moisture conditions for the series, but by use of damp air and a tight box and of air saturated with steam the desired result was secured fairly well. The advantage of using specimens of small size is obvious.

For drying the material a room about 10 by 14 feet, with walls and ceiling made impervious to moisture by cement and brick, is fitted

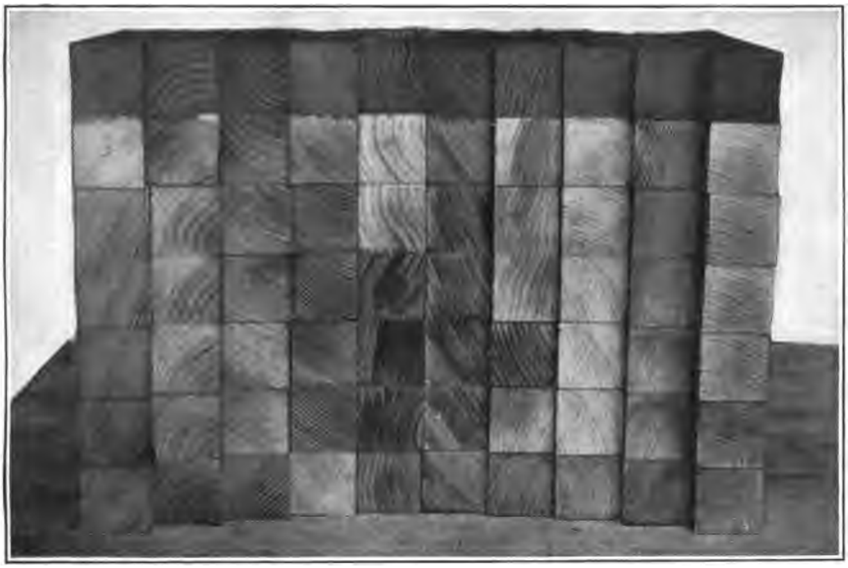

FIG. 1.—TEN SERIES FOR COMPRESSION TESTS (THE GREEN PIECES ARE OMITTED). CHESTNUT.

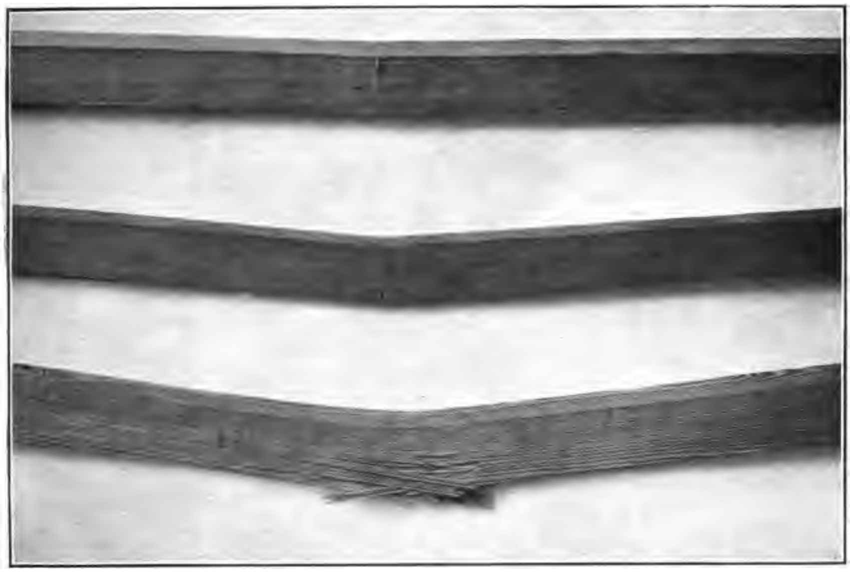

FIG. 2.—MANNER OF FAILURE UNDER BENDING TESTS OF GREEN, AIR-DRY, AND KILN-DRY LONGLEAF PINE.

SAMPLES OF SPECIMENS FOR COMPRESSION TESTS, AND THE RESULT OF BENDING TESTS.

with steam coils, above which is an open rack for holding the sticks. Circulation of air may be obtained by a door at one end of the room and a small window near the ceiling at the other end. It is also arranged that live steam may be allowed to escape into the room. There is a self-recording thermometer, and a hygrometer indicates the humidity of the air.

When the test specimens were prepared those which were to be tested green were either tested at once or placed in a tight, zinc-lined box and kept damp until tested. Others were immersed in the tank to soak. Some were stood in the room to air dry. The rest were placed on the rack in the dry kiln. The blocks for compression parallel to grain were treated in 8-inch lengths, and those for shearing in 6 inch, all being cut at the time of the test to the exact size wanted. Checking is very apt to occur at the two ends, but by cutting off these ends after drying in this way freedom from checks is secured in the test specimen and the surfaces are squared up.

Since the drying occurs most rapidly from the ends, the short blocks were usually stood erect with the ends covered during the first week or two in the kiln, in order to secure more uniform drying and less checking on the ends.

When the specimens were all arranged live steam was turned into the room at a low temperature (about 80° F.) for several days. The temperature was then gradually raised to about 130° or 140° F., the humidity being from 75 to 80 per cent. This steam bath was continued for from one to three weeks, the temperature falling somewhat over night. During these weeks it was found that the wood lost weight rather rapidly, even with the air full of clouds of condensed steam.[a] The live steam was then turned off, and the temperature was kept between about 120° and 140° F. for two or three weeks longer. Some circulation of air was permitted as needed.

All the specimens were weighed before being treated, and sample ones were weighed periodically during the drying or soaking process, to keep track of their condition. When the proper weight was reached they were taken out, and usually allowed to remain in the room several days to equalize the distribution of moisture, or were placed in an air-tight tin cylinder, or desiccator, containing lumps of calcium chlorid in open dishes. They were then weighed and tested, the end-compression blocks being first cut to exact lengths on the smooth-cutting circular saw, which gave true ends. The shear blocks were also cut to 3-inch lengths at this stage and trimmed in the form for shearing.

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[a] The distinction between this method and that of subjecting the wood to saturated steam or steam under pressure should be noted, since the latter has quite a different effect. (See footnote, p. 116.)

Some pieces were still further dried, after they had been thoroughly kiln-dried, by being placed in the drying oven and heated nearly to the boiling point during the daytime for several days. This was not done with the beams, however, as they were too long to go in the oven. Under this oven drying the pieces lost all but 1 or 2 per cent of their moisture and showed a correspondingly greater strength than the kiln-dried material. With the chestnut, still greater dryness was attained by placing some of the endwise compression blocks and the shear blocks in the vacuum oven, at 20 inches vacuum and at nearly the boiling temperature, for four or five hours. The result was not significantly different from the ordinary oven-dry tests.

REABSORPTION OF MOISTURE.

The pieces for the reabsorption tests, which form a part of the regular "series," were thoroughly kiln dried, along with the others, as just described, then taken out and allowed to stand in the air or immersed under water in the tank, as the case might be, for about a month.

Now, the moisture in the wood may exist in two states, either as imbibed moisture, which is absorbed by the cell walls—that is, the substance of the wood itself—or as free water, which merely fills the pores or cavities of the wood, like honey in a comb. And if a piece of dry wood be immersed in water and the moisture content be then determined, it is impossible to distinguish between the free and the imbibed water, so that the figure obtained is apt to indicate too great a moisture degree for the corresponding strength value, since this figure includes the free water, which does not influence the strength. This effect of soaking is not shown, however, in pieces which have been thoroughly soaked, since the strength in this condition has reached its lowest point anyway and is constant. It is evident only at intermediate points. It is plain, therefore, that to avoid confusion in determining the loss of strength due to reabsorption, except for completely soaked wood, the moisture should not be allowed to take the form of free water, and that for this reason the piece should not be placed in contact with water, but should be suffered to reabsorb moisture from the air. (This fact probably accounts for the reabsorption point P on fig. 8 falling above the curve.)[a]

It must also be noticed that during the drying process the outer surface of a piece of wood is necessarily somewhat drier than the interior, whereas during the reabsorption process the reverse is the

[a] This question of the state in which the moisture exists in the specimen, and of its distribution, is of great significance and will therefore be fully discussed in connection with the explanation of the "fiber-saturation point." (See p. 82.)

case. This is of special significance in the case of beams, where it is the surface fibers which have the greatest relative influence upon the strength, and it must be taken into consideration in the beam tests.

All the reabsorption pieces, as will be seen from the tables and diagrams, show a decided loss in strength due to kiln-drying. That this loss is not due to the volatile oil driven off in heating seems probable, inasmuch as the spruce and chestnut show as great a loss in strength as the longleaf pine, which contains much more oil than the two other species.

The detailed process to which each "set" of tests was subjected in treatment preparatory to testing is given in the twelve large tables of individual tests (numbered 1 to 12.)

THE MECHANICAL TESTS.

SIZE OF THE TEST SPECIMENS.

The size of the test specimens is an important consideration. If the specimens are too large it is not only impossible to secure enough perfect pieces from one tree to form a "series," but the drying process becomes very difficult and irregular, and requires a very great length of time, besides causing checks and internal stresses. On the other hand, the smaller the dimensions of the test piece the greater is the proportionate effect of the inherent factors affecting the strength; the surface becomes greater in proportion to the volume, and imperfections and inaccuracies have a greater relative influence. Moreover, the smaller the specimen, the fewer annual rings it contains, so that there is more chance for variation due to irregularities in grain. The relation of the size to the testing operations must also be considered. From this standpoint that size is best which admits the least error in the working of the testing machine and in the observation of the readings.

The size which was selected as the most suitable for all purposes, and which has proved by experience to be the most satisfactory, was 2 by 2 inches square, and of whatever length desired.

The specimens were cut at first several inches longer than the required size, except the beams and those for compression at right angles to grain, in order to avoid injury and checking in drying, as already explained, and were subsequently cut to the exact size at the time of testing.

COMPRESSION PARALLEL TO GRAIN.

(Tables 1, 2, 3, 4.)

The tests of compression parallel to grain were made chiefly on the Olsen machine, but as the strength of the driest pieces ran above its capacity, a few of the tests were made upon the Riehlé machine.

The compression blocks had been planed, as described, 2 by 2 inches square when green, in 8-inch lengths, and subjected to whatever treatment was necessary in this size. At the time of the test the two ends were cut off on a special smooth-cutting circular saw in order to secure true bases for the compression blocks of the machine to act against. The longleaf pine was thus trimmed to 6-inch lengths for the test specimens, but the spruce, except where otherwise noted in one or two sets (see Table 3), and the chestnut were trimmed to 5¾-inch lengths, which proved to be more suitable for the Riehlé machine.

The average speed of compression for all end-compression tests was about 0.01 inch per minute, or 0.0017 inch per minute per inch of length.

It should be noted that there are three ways in general in which the load can be applied: (1) By constant speed of deflection, (2) by constant rate of fiber stress, and (3) by a constant load allowed to remain until rupture occurs. The first of these methods is the one used in this investigation. With a constant speed of deflection it follows that the rate of fiber stress will vary according to the qualities of each specimen. In these compression tests the rate of fiber stress (below the true elastic limit), expressed in pounds per square inch per minute, is summed up in the following table:

Species.	Green.			Dry.		
	Average.	Maximum.	Minimum.	Average.	Maximum.	Minimum.
Longleaf pine	1,913	2,090	1,470	2,390	2,890	1,930
Spruce	1,100	1,400	990	2,200	2,500	2,100
Chestnut	1,100	1,300	720	2,100	2,500	1,400

The specimens were stood on end upon the platform of the machine in the usual manner, and the solid crosshead block, as a rule, pressed directly upon the upper end. In a few cases, however, a ball-and-socket block was placed between the upper end of the specimen and the crosshead block to adjust any nonparallelism of the two ends of the specimen. With true ends, however, the ball-and-socket joint should be unnecessary.

For measuring the deflections a simple deflectometer was used. It consists essentially of a simple lever, suitably arranged and accurately adjusted, so that when placed in contact with the crosshead of the machine its motion is magnified ten times. The readings are indicated on a vertical scale to thousandths of an inch by use of a vernier. This instrument is more convenient and suitable to tests of this kind than the usual form of compressometer used in metal tests, owing to the difficulty of properly clamping the instrument to so soft a material as wood, and the necessity of taking the readings "on the fly" without interruption. It must be noted,

FIG. 1.—LONGLEAF PINE.

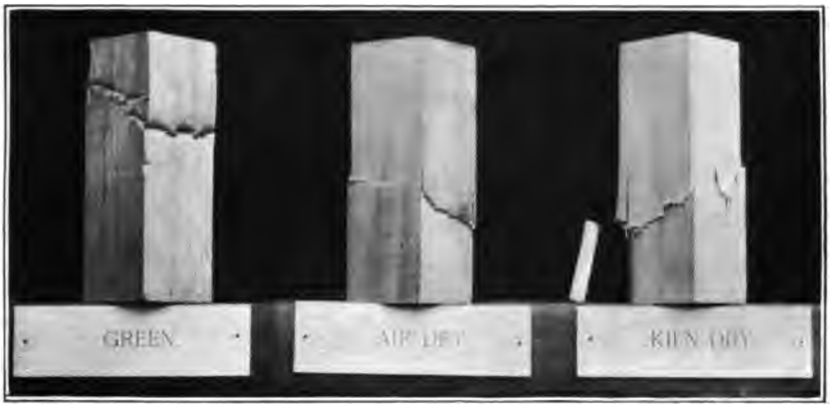

FIG. 2.—SPRUCE.

FIG. 3.—CHESTNUT.

MANNER OF FAILURE IN COMPRESSION TESTS OF WOOD IN DIFFERENT MOISTURE CONDITIONS.

however, that this deflectometer indicates actually the movement of the crosshead of the machine relative to the base upon which the deflectometer is resting instead of the deflection of the test piece itself. While this introduces a factor of error, which lowers the value obtained for the modulus, the tests, all made in the same way, are nevertheless comparable. In the diagrams the stress and strain curve was found to be uniform above a total load of 2,000 pounds for the green and about 4,000 pounds for the kiln-dried. All the calculations were based on the straight portion of the curve by extending it as a straight line downwards to the zero load, thus eliminating any irregularities at the initial part of the test. The local compression of the top and bottom of the specimen in contact with the surfaces of the testing machine will render the values of the modulus of elasticity less than those which will result from tests upon long specimens. The methods described will, however, give general values of the yield point, and will determine the relative stiffness of wood at various stages of dryness. (See fig. 1.)

Readings of the deflectometer were taken at regular intervals, every 1,000 to 2,000 pounds, according to the strength of the specimen, up to and beyond the maximum point, which was also noted. The maximum point is the ultimate strength. The specimen does not give way suddenly except in the extremely dry condition, but the load increases more and more slowly until it reaches a maximum, and then begins to decrease rather more rapidly at first, but presently slowing up again and holding nearly constant for a long time, the compression uniformly increasing all the while. The wet pieces show the least decided maximum point, especially with chestnut, the load sometimes remaining practically the same for a long time, while the dry pieces, especially longleaf pine, give way suddenly. Usually the only indication of failure at first is this maximum point, as shown by the scale beam, no visible effect being produced upon the specimen until the compression has been carried considerably beyond the point of failure. A ridge then appears running around the specimen, caused by a buckling of the walls of the fibers, as shown in Pl. II. In the very dry specimens the failure occurs by a splitting up of the entire piece before any buckling takes place.

The elastic limit is not as clearly defined as in metal tests, there being no "drop of the beam" at this point, but simply a slight increase in the amount of deflection for the same increment of load. It is more accurately located from the stress and strain diagram, which was the method used in all the calculations.

The effect of moisture upon the relation of stress and strain is well shown by fig 1, page 22, which is taken from the regular series. As the specimen becomes drier the curve becomes steeper and the maximum point becomes more abrupt. In this figure the tangent

line, by which the elastic limit is located and from which the modulus of elasticity is calculated, is also shown.

The modulus of elasticity appears to be a more uncertain quantity than the maximum strength or the elastic limit, and more susceptible to the influence of extrinsic conditions. As will be seen from the diagrams in fig. 1, the resoaked pieces show marked decrease in the steepness of the curve as compared with the green or soaked speci-

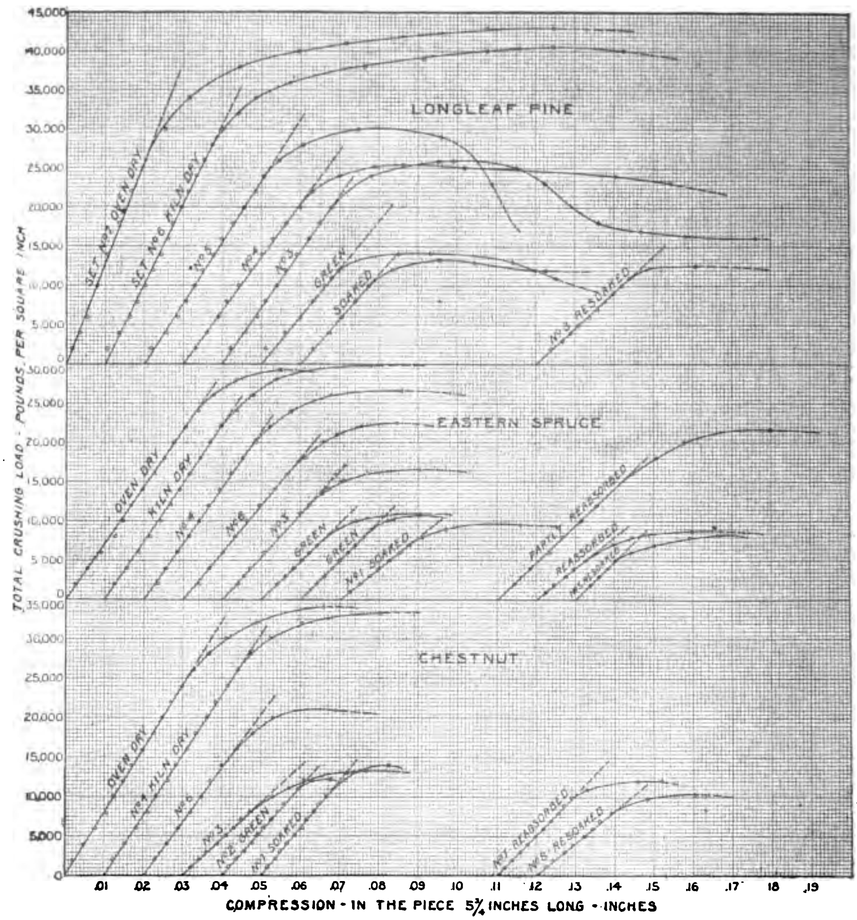

FIG. 1.—Stress-strain diagrams of single series of tests of compression parallel to grain.

mens. Green spruce specimens left for several months in the damp box showed the same effect in a surprising degree, although the other values had not fallen off. The cause of this decrease in stiffness is not apparent, since no fungous growth or other visible change of any kind had taken place. Temperature appears to influence the stiffness of wet wood very greatly, especially of chestnut. This subject will again be referred to on page 84.

In addition to a record of the source of the lumber and its treatment prior to testing, the following data were recorded for each test upon the blank prepared for this purpose: The date of test, number of specimen (which indicates both the series and the set), the weight when first prepared (green), the weight before and after trimming at time of test, the cross-sectional area to hundredths of a square inch, the deflection and load at the intervals chosen and at the maximum point, the time of starting and ending the test (and occasionally intermediate times), a rough sketch showing how the failure occurred, the weights of the various moisture disks, and any remarks pertinent to the test or manner of failure.

As soon as the test was made, or shortly afterwards, the moisture disks were cut on a smooth-cutting circular saw and immediately weighed to the nearest centigram on a fine Becker chemical balance.

Sections about 3 inches long were taken from a number of the compression test specimens out of each series of the longleaf pine, from which the amount of volatile oil was determined, as explained on page 127. This oil content was found to be small compared with the moisture, the average amount for normal wood being 0.47 per cent, and ranging from 0.10 to 1.3 per cent of the dry weight. Very little, if any, was lost in the process of kiln-drying. An abnormally resinous series, however, yielded 7 per cent of volatile oil.

TABLE 1.—*Longleaf pine. Compression parallel to grain. Size 2 by 2 by 6 inches.*

The pieces for compression tests were taken from 4-inch planks procured in July, 1903, as a lot from Tifton, Ga., and said to have been cut in that vicinity in the spring of 1903. The large sticks were kept in water at the mill in New Haven and sawed into planks when ordered. Specimens were prepared July 16 to August 10. Treated in 8-inch lengths.

No. of test piece.	Weight when cut (8 inches long).	Weight at test. 8 inches long.	Weight at test. 6 inches long.	Rings per inch.	Moisture at break.	Volatile oil.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Elastic resilience per cubic inch.	Specific gravity.	Crushing strength per sq. in. of original area.	Condition and treatment.
1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*	*Inch-lbs.*		*Lbs.*	
101	372	....	265	......	21.6	....	4.00	20,750	5,190	4,500	1,165	7.96	0.67	5,190	Green. Tested directly.
111	365	....	270	20	22.2	0.21	4.00	18,100	4,620	4,000	1,159	6.26	.69	4,520	
121	376	....	279	24	21.9	.30	4.00	19,900	4,980	3,500	1,373	4.54	.71	4,980	
131	396	....	296	27	18.7	1.12	4.00	20,700	5,180	4,300	1,452	6.50	.75	5,180	
141	286	....	212	25	18.1	....	4.00	14,150	3,540	3,000	874	5.17	.54	3,540	
151	....	....	261	......	19.8	.48	4.00	20,750	5,190	3,600	1,059	6.83	.66	5,190	
Average	359	....	264	24	20.4	.53	4.00	19,058	4,767	3,817	1,180	6.21	.67	4,767	
102	353	434	300	......	37.9	.17	4.05	18,800	4,640	3,500	1,364	4.33	....	4,700	Soaked. Soaked in water for 29 days from Aug. 12 (outdoors).
112	359	421	293	19	34.7	....	4.08	19,600	4,810	4,200	1,213	6.83	....	4,900	
122	374	444	308	23	35.1	.25	4.05	20,300	5,020	3,500	1,429	5.18	....	5,080	
132	407	468	329	26	34.0	1.10	4.08	20,400	5,000	3,900	1,423	4.08	....	5,010	
142	285	367	249	24	39.8	.56	4.08	13,350	3,270	2,600	841	3.84	....	3,340	
152	....	426	296	......	33.8	....	4.07	18,400	4,520	3,400	1,092	6.73	....	4,600	
Average	356	427	296	23	35.7	.52	4.07	18,475	4,543	3,517	1,227	5.16	....	4,605	
103	349	....	246	......	14.0	.11	(3.79)	22,850	6,030	4,900	1,143	9.04	....	5,710	Partly dry. Dried in kiln with steam at about 115° F. for 2 days.
113	352	....	241	17	15.1	.22	(3.89)	25,500	6,560	4,800	1,344	7.88	....	6,380	
123	381	....	267	25	14.4	.26	(3.79)	29,350	7,750	5,800	1,537	10.8	....	7,340	
133	404	....	290	23	14.1	....	(3.87)	27,900	7,220	5,000	1,535	7.08	....	6,980	
143	282	....	196	31	9.7	....	(3.78)	25,900	6,860	5,300	1,161	12.5	....	6,480	
153	339	....	240	......	12.5	.34	(3.84)	27,000	7,040	5,700	1,129	14.5	....	6,750	
Average	351	....	245	24	13.3	.23	(3.83)	26,417	6,910	5,250	1,308	10.30	....	6,607	

104	351	....	245	......	13.3	.10	3.76	29,250	7,790	6,400	1,602	12.2	....	7,340	Air-dry. Dried in kiln with steam at about 115° F. for 3 days, then stood in room for 13 days.
114	370	....	249	19	12.4	.19	3.81	a(32,000)	a (8,400)	6,400	1,575	13.2	....	a(8,000)	
124	374	....	255	24	12.3	....	3.74	a(35,000)	a (9,370)	6,400	1,697	12.4	....	a(8,750)	
134	382	....	269	22	12.6	....	3.81	30,230	7,940	6,300	2,100	9.31	....	7,560	
144	282	....	192	24	10.1	.27	3.80	25,400	6,680	4,700	1,109	11.5	....	6,350	
154	337	....	234	22	10.5	....	3.80	26,550	6,990	5,300	1,353	10.2	....	6,640	
Average	349	....	241	22	11.9	.19	3.79	29,737	7,861	5,917	1,573	11.47	....	7,440	
105	346	....	231	......	8.5	.15 .18	3.67	38,200	10,430	7,600	1,775	16.4	....	9,560	Partly kiln-dried. Kiln-dried as above with steam for 5 days, then stood in room 4 days and returned to kiln with dry heat of about 120° F. for 12 days.
115	365	....	237	29	7.65	.23	3.67	37,800	10,300	8,300	1,693	20.4	....	9,450	
125	367	....	239	24	7.41	....	3.63	39,300	10,820	9,400	1,905	23.2	....	9,830	
135	407	....	283	30	9.04	1.30	3.70	37,550	10,140	7,800	1,871	15.9	....	9,390	
145	....	....	189	27	7.08	.27	3.66	30,000	8,200	6,600	1,329	16.6	....	7,500	
155	350	....	240	21	7.32	.40	3.77	37,300	9,900	7,400	1,540	17.2	....	9,330	
Average	367	....	236	26	7.83	.42	3.68	36,692	9,965	7,850	1,686	18.3	....	9,177	
106	332	280	215	......	3.63	.11	3.67	44,000	12,000	7,800	1,635	17.6	.60	11,000	Kiln-dry. Kiln-dried 20 days, with steam 4 days at about 115° F., and dry heat 16 days at 115° to 122° F.
116	378	312	232	35	3.64	....	3.65	51,500	14,110	11,600	1,821	36.0	.65	12,880	
126	361	300	227	30	3.36	....	3.54	50,500	14,270	9,600	2,117	22.4	.65	12,630	
136	413	362	273	35	4.94	....	3.65	49,300	13,500	9,300	1,761	24.9	.76	12,330	
146	....	256	191	31	3.19	....	3.69	40,500	10,980	7,600	1,654	17.8	.53	10,130	
156	345	300	218	22	3.48	.44	3.63	44,700	12,310	7,900	1,574	18.6	.61	11,180	
Average	366	302	226	31	3.71	.27	3.64	46,750	12,861	8,967	1,760	22.9	.63	11,691	
107	336	279	209	......	1.87	....	3.61	46,620	12,910	8,900	1,862	21.0	.588	11,660	Oven-dry. Kiln-dried as last for 20 days, then dried in oven at about 208° F. for several days.
117	372	300	225	27	1.36	....	3.58	56,290	15,720	12,300	2,287	33.7	.640	14,070	
127	361	297	223	22	1.27	....	3.60	54,330	15,100	10,500	2,222	25.6	.630	13,590	
137	393	337	253	38	2.13	....	3.60	56,450	15,670	9,500	2,000	22.4	.715	14,110	
147	....	248	186	39	1.27	.42	3.60	43,080	11,980	7,200	2,095	11.8	.525	10,770	
157	343	291	218	21	1.06	.50	3.65	49,910	13,670	8,500	1,672	22.1	.608	12,480	
Average	361	292	219	29	1.49	.46	3.61	51,113	14,125	9,483	2,023	22.8	.618	12,780	

Reabsorption.

108	346	301	225	......	12.5	....	3.75	29,700	7,930	5,600	1,316	11.9	....	7,420	Resoaked. Kiln-dried as No. 106 about 30 days, then soaked for 15 days.
118	366	349	232	33	11.6	....	3.72	35,200	9,470	5,600	1,936	9.1	....	8,800	
128	375	342	255	25	14.8	....	3.83	31,600	8,190	5,800	2,062	8.02	....	7,900	
138	389	351	263	38	13.6	....	3.88	32,200	8,310	6,200	1,622	4.5	....	8,050	
148	....	265	197	......	15.2	....	3.90	22,060	5,660	3,500	960	8.52	....	5,520	
158	342	311	218	23	14.1	.38	3.90	27,500	7,050	4,200	1,591	5.37	....	6,870	
Average	364	320	232	30	13.6	.38	3.83	29,710	7,768	5,150	1,581	8.74	....	7,427	

a Estimated above 30,000 pounds on machine.

TABLE 1.—*Longleaf pine. Compression parallel to grain. Size 2 by 2 by 6 inches*—Continued.

Reabsorption—Continued.

No. of test piece.	Weight when cut (8 inches long).	Weight at test. 8 inches long.	Weight at test. 6 inches long.	Rings per inch.	Moisture at break.	Volatile oil.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *E*.	Elastic resilience per cubic inch.	Specific gravity.	Crushing strength per sq. in. of original area.	Condition and treatment.
1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*	*Inch-lbs.*		*Lbs.*	
109........	338	443	297	28	74.7	....	4.06	14,250	3,510	2,710	810	4.23	....	3,560	Resoaked. Kiln-dried as No. 106 for 30 days, then immersed in water outdoors from Sept. 9, 1903, to Apr. 27, 1904, with short intermissions, being frozen during cold weather.
119........	363	....	334	25	41.7	....	4.12	16,950	4,120	....	....	....	....	4,240	
129........	380	476	327	25	47.4	....	4.06	19,250	4,740	3,950	1,218	6.36	....	4,810	
139........	383	478	323	36	52.8	....	4.08	19,100	4,676	3,430	1,194	5.33	....	4,770	
149........	....	....	270	38	62.8	....	4.10	12,525	3,060	....	....	....	....	3,130	
159........	341	458	310	24	46.6	....	4.06	16,800	4,140	3,200	953	5.38	....	4,200	
Average.	361	464	310	29	54.3	....	4.08	16,479	4,040	3,323	1,059	5.33	....	4,118	

ABNORMALLY RESINOUS SERIES.

No. of test piece.	Weight when cut (8 inches long).	Weight at test. 8 inches long.	Weight at test. 6 inches long.	Rings per inch.	Moisture at break.	Volatile oil.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *E*.	Elastic resilience per cubic inch.	Specific gravity.	Crushing strength per sq. in. of original area.	Condition and treatment.
161........	523	....	393	17	17.9	7.1	4.00	18,850	4,710	4,000	1,072	7.22	1.00	4,710	The wood of this series was translucent with resin, and contained over 7 per cent volatile oil. The series was therefore not averaged with the rest.
162........	497	543	486	20	23.5	5.5	4.09	19,250	4,710	3,400	1,146	5.05	....	4,810	
163........	444	....	324	20	16.6	5.0	(3.97)	21,000	5,290	4,500	975	9.75	....	5,250	
164........	519	....	372	19	15.0	....	3.93	25,800	6,570	5,600	985	15.4	....	6,450	
165........	495	....	347	27	12.2	5.4	3.78	33.300	8,820	7,400	1,719	15.8	....	8,550	
166........	449	395	298	30	5.44	....	3.56	50,000	14,030	10,700	2,023	29.6	.85	12,500	
167........	443	382	286	31	4.75	3.0	3.54	55,760	15,730	11,300	2,424	24.6	.822	13,940	

Reabsorption.

No. of test piece.	Weight when cut (8 inches long).	Weight at test. 8 inches long.	Weight at test. 6 inches long.	Rings per inch.	Moisture at break.	Volatile oil.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *E*.	Elastic resilience per cubic inch.	Specific gravity.	Crushing strength per sq. in. of original area.	Condition and treatment.
168........	435	391	292	29	11.2	....	3.74	35,340	9,460	5,900	1,925	9.23	....	8,840	
169........	432	496	342	26	25.8	....	4.03	18,000	4,470	3,470	1,116	5.42	....	4,500	

TABLE 2.—*Spruce. Compression parallel to grain. Lot of 1904. Size 2 by 2 by 5¾ inches.*

Three-inch planks procured March 19, 1904, as a fresh cargo from northern Maine. Specimens prepared from March 22 to April 8. The strips were kept damp over water in a tank until treated.

No. of test piece.	Weight when cut (8 inches long).	Weight at test.		Rings per inch.	Moisture.		Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Specific gravity.	Condition and treatment.
		8 inches long.	5¾ inches long.		At break, disk *a*.	Elsewhere, disk *b*.							
1	2	3	4	5	6	7	9	10	11	12	13	15	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*		
C 101	238	309	207	20	73.0	45.4	3.99	9,420	2,360	1,800	720	....	Soaked. Soaked in water for 44 days, beginning Apr. 14 (outdoors).
C 121	239	314	211	21	44.4	46.8	4.04	8,780	2,170	1,610	425	....	
D 101	265	309	207	12	62.5	62.1	4.00	8,950	2,240	1,750	614	....	
D 121	247	310	208	15	38.9	46.0	4.03	10,300	2,560	1,980	714	....	
D 141	243	311	211	14	68.4	46.2	4.04	9,820	2,430	1,730	713	....	
F 101	223	295	195	19	43.8	47.1	4.00	9,310	2,330	1,750	600	....	
G 101	236	306	209	9	49.2	50.0	3.93	8,910	2,270	1,530	656	....	
H 101	245	310	207	11	43.1	46.9	4.00	9,600	2,400	1,750	568	....	
I 101	250	313	211	15	72.5	44.6	4.01	10,120	2,530	1,500	694	....	
I 121	257	321	217	11	....	....	3.95	9,950	2,520	1,900	727	....	
J 101	262	331	213	18	45.4	44.2	3.96	10,730	2,710	2,140	727	....	
Average	246	312	209	15.5	54.1	47.9	3.99	9,626	2,411	1,767	651	....	
C 102	233	233	172	21	26.6	27.5	3.98	11,190	2,810	1,760	855	0.46	Green. The alternate numbers were taken from opposite ends of the same stick from which all the other specimens in the series were cut. Remained in damp box 7 days, until tested.
C 112	243	243	175	20	29.0	29.9	3.95	9,950	2,520	2,100	485	.47	
C 122	239	239	171	21	24.9	24.9	3.99	11,070	2,780	1,880	662	.45	
C 132	231	231	165	20	24.4	24.2	3.92	11,200	2,860	1,960	734	.45	
D 102	258	258	188	12	40.8	40.6	4.00	9,620	2,400	1,750	709	.50	
D 112	248	248	179	16	32.6	32.6	4.02	10,620	2,650	1,990	715	.47	
D 122	243	243	175	17	25.4	25.6	4.01	12,900	3,220	2,740	815	.46	
D 132	....	....	....	18	26.9	27.0	3.97	12,200	3,070	2,520	814	....	
D 142	240	240	172	14	27.5	28.7	4.03	11,000	2,730	2,110	658	.45	
D 152	241	241	173	16	30.8	30.6	3.96	11,000	2,780	2,270	765	.46	
F 102	223	223	161	19	26.7	26.8	3.98	11,180	2,810	1,880	738	.43	
F 112	234	234	169	16	29.0	28.7	3.97	11,030	2,780	2,260	687	.45	
G 102	239	239	173	12	26.3	25.9	3.89	11,750	3,020	2,180	740	.47	
G 112	235	235	170	13	26.5	26.6	3.94	11,980	3,040	1,900	918	.46	
H 102	249	249	178	11	30.0	30.6	3.99	10,780	2,700	2,250	721	.47	
H 112	235	235	170	13	27.4	27.9	3.91	11,000	2,820	1,920	736	.46	
I 102	258	258	182	16	28.6	28.6	3.98	12,400	3,120	2,510	951	.48	
I 112	257	257	185	12	31.2	31.5	3.99	11,780	2,950	2,000	918	.49	
I 122	260	260	188	13	34.9	35.0	3.96	10,650	2,690	1,770	831	.50	
I 132	255	255	184	10	32.7	32.1	3.96	11,000	2,780	2,270	726	.49	
J 102	260	260	186	17	31.2	31.7	3.96	12,650	3,200	2,520	844	.50	
J 112	245	245	176	17	26.8	27.1	3.97	13,430	3,390	2,390	828	.47	
Average	244	244	176	16	29.1	29.3	3.97	11,379	2,869	2,133	766	.469	

TABLE 2.—*Spruce. Compression parallel to grain. Lot of 1904. Size 2 by 2 by 5¾ inches*—Continued.

No. of test piece.	Weight when cut (8 inches long).	Weight at test.		Rings per inch.	Moisture.		Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *E*.	Specific gravity.	Condition and treatment.
		8 inches long.	5¾ inches long.		At break, disk *a*.	Elsewhere, disk *b*.							
1	2	3	4	5	6	7	9	10	11	12	13	15	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*		
C 103	236	207	149	19	14.4	14.7	3.75	17,175	4,580	2,670	756	....	Air-dried. Stood on end in room with ends covered 12 days, in 8-inch lengths.
C 123	234	211	152	23	13.7	....	3.79	16,600	4,380	2,190	826	....	
D 103	250	209	151	12	15.1	....	3.81	16,675	4,380	3,150	611	....	
D 123	241	219	158	19	14.6	....	3.82	18,775	4,920	3,670	785	....	
D 143	240	212	154	16	14.5	....	3.86	17,775	4,600	2,720	745	....	
F 103	221	198	143	16	13.7	13.8	3.74	17,450	4,670	5,080	840	....	
G 103	235	211	153	12	14.0	13.2	3.69	17,850	4,840	3,800	821	....	
H 103	250	215	156	12	15.5	13.5	3.82	16,450	4,310	2,880	851	....	
I 103	249	221	163	15	14.9	13.9	3.70	19,760	5,350	3,110	1,085	....	
I 123	259	223	161	13	15.4	14.3	3.67	19,050	5,200	4,370	1,060	....	
J 103	258	222	160	19	15.3	14.3	3.73	19,230	5,160	3,890	989	....	
Average	243	213	155	16	14.6	14.0	3.76	17,890	4,763	3,412	852	....	
C 104	238	196	139	18	5.2	4.6	3.60	30,300	8,430	6,200	1,354	....	Partly kiln-dried. Kept in room 6 days; then 2 days in kiln with steam at 80° F., 4 days in kiln with steam at 122° F., 7 days in kiln, dry heat, at 120° to 130° F. Treated in 8-inch lengths, with ends covered.
C 124	249	196	143	13	5.9	4.6	3.69	25,310	6,860	5,290	1,249	....	
D 104	242	192	139	19	6.1	6.1	3.67	26,430	6,930	4,770	1,521	....	
D 124	247	202	146	14	6.5	6.4	3.71	28,590	7,700	4,590	1,183	....	
D 144	243	195	142	16	6.0	5.0	3.71	28,000	7,550	4,590	1,200	....	
F 104	236	182	131	12	5.4	5.1	3.64	26,670	7,340	5,080	1,272	....	
G 104	244	193	139	11	5.9	6.2	3.65	26,890	7,380	4,660	1,249	....	
H 104	245	198	142	14	6.1	6.1	3.66	26,650	7,290	5,060	1,130	....	
I 104	248	198	144	12	6.3	6.2	3.55	29,450	8,300	6,480	1,326	....	
I 124	252	201	145	19	6.3	5.5	3.62	26,100	7,220	7,190	1,418	....	
J 104	248	203	147	15	6.5	5.9	3.71	32,600	8,790	7,820	1,395	....	
Average	245	196	142	15	6.0	5.6	3.65	27,910	7,617	5,612	1,300	....	

C 106	235	193	138	14	9.4	9.6	3.63	24,400	6,720	4,210	1,076	....	Partly kiln-dried. Same as last, except dry heat for only 3 days.
C 126	240	205	147	19	9.3	8.9	3.73	22,025	5,910	3,380	882	....	
D 106	266	201	144	14	10.0	....	3.77	19,675	5,220	4,240	770	....	
D 126	243	206	146	20	10.0	8.7	3.72	24,400	6,570	5,380	1,005	....	
D 146	244	200	143	15	9.8	9.2	3.75	22,500	6,000	3,870	892	....	
F 106	299	205	147	18	10.3	9.5	3.73	24,000	6,440	4,290	1,020	....	
G 106	233	198	143	13	9.8	9.2	3.65	23,325	6,400	4,660	1,125	....	
H 106	243	205	148	11	10.1	9.8	3.75	22,380	5,970	4,000	923	....	
I 106	256	205	148	14	10.2	9.6	3.60	25,050	6,960	6,110	1,100	....	
I 126	249	207	149	15	10.9	9.7	3.59	24,600	6,860	5,850	1,111	....	
J 106	243	206	148	20	10.4	9.5	3.64	24,630	6,770	5,360	1,129	....	
Average	250	203	146	17.7	10.0	9.4	3.68	23,360	6,347	4,668	1,003	....	
C 107	239	186	135	15	3.3	3.3	3.59	32,000	8,920	6,000	1,540	0.40	Kiln-dried. Same as No. 104, except dry heat for 14 days.
C 127	248	202	147	21	3.3	3.7	3.69	27,660	7,500	4,880	1,052	.42	
D 107	289	195	142	13	3.4	3.7	3.72	30,630	8,240	5,380	1,030	.40	
D 127	233	190	137	21	3.4	3.4	3.62	31,310	8,650	5,540	1,405	.40	
D 147	259	199	145	14	3.3	3.4	3.68	30,300	8,250	5,710	1,230	.42	
F 107	307	190	137	18	3.3	3.3	3.58	31,400	8,770	6,150	1,225	.41	
G 107	247	191	138	12	3.4	3.6	3.58	30,520	8,530	6,700	1,420	.41	
H 107	242	191	138	11	3.5	3.4	3.65	29,840	8,180	6,020	1,167	.40	
I 107	248	192	139	11	3.4	3.2	3.61	33,600	9,310	6,650	1,349	.41	
I 127	250	191	139	11	3.4	3.4	3.62	32,560	9,000	6,640	1,301	.41	
J 107	247	197	141	19	3.5	3.5	3.62	34,230	9,460	7,190	1,405	.41	
Average	255	193	140	15.1	3.4	3.4	3.63	31,300	8,619	6,078	1,284	.408	
C 107_1	242	186	134	15	1.7	1.0	3.63	33,600	9,270	5,650	1,540	.39	Oven-dried. Same as No. 104, except dry heat for 9 days and then placed in oven at about 208° F. for 8 hours per day for 7 days.
C 127_1	249	201	145	18	1.3	1.6	3.64	30,400	8,360	6,050	1,051	.42	
D 107_1	304	190	137	13	1.7	1.0	3.67	31,740	8,650	5,450	1,177	.40	
D 127_1	234	186	134	17	1.6	1.0	3.61	33,380	9,250	6,100	1,253	.39	
D 147_1	245	186	134	15	1.1	1.4	3.71	30,420	8,200	6,480	1,075	.38	
F 107_1	299	185	133	19	1.1	1.6	3.53	32,330	9,150	7,090	1,292	.40	
G 107_1	241	191	138	12	1.1	1.1	3.57	32,220	9,030	7,010	1,256	.41	
H 107_1	240	189	135	11	1.2	1.1	3.61	29,200	8,100	6,510	1,138	.40	
I 107_1	252	194	140	14	1.2	1.2	3.55	37,900	10,670	8,460	1,620	.42	
I 127_1	250	192	137	12	1.3	1.1	3.48	36,050	10,360	7,480	1,590	.42	
J 107_1	252	196	140	19	1.2	1.2	3.46	36,900	10,660	8,680	1,650	.43	
Average	255	191	137	15	1.3	1.2	3.58	33,100	9,255	6,815	1,332	.405	

TABLE 2.—*Spruce. Compression parallel to grain. Lot of 1904. Size 2 by 2 by 5¾ inches*—Continued.

REABSORPTION.

No. of test piece.	Weight when cut (8 inches long).	Weight at test. 8 inches long.	Weight at test. 5¾ inches long.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. Elsewhere, disk *b*.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit *F*.	Modulus of elasticity, *Ec*.	Dry specific gravity.	Weight when kiln-dry (8 inches long).	Moisture, disk *x*. Outside.	Moisture, disk *x*. Inside.	Condition and treatment.
1	2	3	4	5	6	7	9	10	11	12	13	15	16	17	18	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*		*Grams.*	*Per cent.*	*Per cent.*	
C 108	246	203	145	15	9.9	....	3.79	20,485	5,410	3,700	600	....	185	10.6	8.5	Reabsorbed. Same as 104, except dry heat for 22 days; then stood in room with ends covered for 23 days during May and June. Treated in 8-inch lengths.
C 128	238	208	150	20	10.1	....	3.76	19,715	5,250	1,730	672	....	190	10.9	8.5	
D 108	280	205	148	14	10.1	....	3.79	21,875	5,780	3,830	755	....	187	10.6	10.1	
D 128	242	209	150	19	9.4	....	3.90	24,205	6,220	5,000	738	....	192	10.4	7.6	
D 148	241	203	145	15	9.9	....	3.86	21,175	5,490	3,760	606	....	187	10.4	9.0	
F 108	224	192	138	16	9.6	....	3.73	21,050	5,650	2,680	870	....	177	....	....	
G 108	243	207	149	12	9.7	....	3.75	23,075	6,160	3,200	1,028	....	190	....	....	
H 108	240	205	147	11	9.9	....	3.78	21,625	5,740	3,700	725	....	187	....	....	
I 108	250	210	152	14	9.6	....	3.70	23,750	6,420	4,870	666	....	193	....	....	
I 128	261	....	150	10	10.3	....	3.70	22,550	6,100	4,870	798	....	192	....	....	
J 108	241	209	....	18	10.0	....	3.69	24,800	6,720	4,610	800	....	192	....	....	
Average	246	205	147	15	9.8	....	3.76	22,210	5,904	3,814	750.7	....	188	10.6	8.7	
C 106_1	241	....	167	15	25.9	....	3.93	9,690	2,460	1,350	461	....	180	....	....	Reabsorbed. Kiln-dried as last for 28 days; stood in room 22 days; then subjected to cool condensed steam 2 days. Kept in damp box for 38 days.
C 126_1	248	....	185	22	28.6	....	3.98	8,000	2,010	1,010	418	....	193	....	....	
D 106_1	272	....	177	14	27.1	....	4.03	8,540	2,120	1,240	465	....	188	....	....	
D 126_1	237	....	175	19	31.1	....	4.00	8,450	2,110	1,750	360	....	185	....	....	
D 146_1	253	....	175	14	25.7	....	3.95	9,585	2,430	1,260	554	....	188	....	....	
F 106_1	322	....	189	19	36.9	....	3.90	8,280	2,120	1,410	461	....	190	....	....	
G 106_1	249	....	170	12	26.5	....	3.82	9,150	2,400	1,050	630	....	185	....	....	
H 106_1	248	....	174	10	27.3	....	3.99	8,800	2,200	1,250	572	....	174	....	....	
I 106_1	249	....	180	12	37.0	....	3.90	8,235	2,110	1,540	492	....	187	....	....	
I 126_1	249	....	173	15	28.5	....	3.88	9,375	2,410	1,930	494	....	188	....	....	
J 106_1	240	....	171	19	35.1	....	3.80	9,300	2,450	1,580	566	....	187	....	....	
Average	255	....	176	16	29.9	....	3.93	8,847	2,256	1,397	497.6	....	186	....	....	

C 105	234	335	197	13	73.0	....	3.98	8,125	2,040	1,250	602	....	180	60.2	35.6	Resoaked. Kiln-dried as last 28 days; then soaked 33 days. Dried in air a few minutes before testing. 8-inch length. Only the ends were wet, which were cut off before testing. All failed on end except D 125. Disks No. *a* contain some free water.
C 125	238	342	205	25	56.1	....	4.08	7,645	1,870	1,100	610	....	190	65.3	31.9	
D 105	250	327	190	16	46.1	....	4.04	8,130	2,010	1,240	542	....	186	45.2	31.0	
D 125	242	334	192	19	36.6	....	4.04	8,510	2,100	1,240	594	....	192	43.2	31.6	
D 145	244	326	192	14	41.0	....	4.05	8,100	2,000	990	693	....	187	43.1	31.0	
F 105	224	326	193	17	59.0	....	4.00	7,665	1,910	1,100	669	....	175	53.6	30.5	
G 105	235	332	193	12	55.8	....	4.00	8,210	2,050	1,000	660	....	185	45.6	32.2	
H 105	242	327	190	11	46.6	....	4.00	8,270	2,070	1,250	715	....	188	47.8	31.1	
I 105	251	337	194	14	47.5	....	3.88	8,385	2,160	1,290	745	....	191	40.8	32.3	
I 125	248	333	192	12	48.9	....	3.98	8,370	2,100	1,250	712	....	190	43.3	33.1	
J 105	245	331	192	19	48.4	....	3.93	9,280	2,360	1,270	721	....	190	37.9	31.8	
Average	241	332	194	16	50.8	....	3.99	8,244	2,061	1,180	660.3	....	186	47.7	32.0	

TABLE 3.—*Spruce. Compression parallel to grain. Lot of 1903. Size, 2 by 2 by 6 inches.*

Three-inch planks procured September 24, 1903, as a fresh cargo from northern Maine. Specimens prepared in October, 1903, and remained in damp box subjected to freezing temperatures outdoors until February 16, 1904. Sizes 2 by 2 by 12 inches.

No. of test piece.	Weight when cut (12 inches long).	Weight at test. 12 inches long.	Weight at test. 6 inches long.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. Elsewhere, disk *c*.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *E*.	Elastic resilience per cubic inch.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	9	10	11	12	13	14	15	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Sq. inches.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 lbs.*	*Inch-lbs.*		
101	365	432	203	15	35.1	36.1	4.11	9,890	2,410	1,820	292	5.62	0.53	Soaked. Soaked in water 23 days from Feb. 16.
111	370	445	209	20	39.4	38.7	4.09	10,250	2,510	1,590	888	1.43	.55	
121	380	450	207	27	37.5	35.7	4.07	10,710	2,630	1,470	276	4.06	.56	
131	390	463	220	28	35.9	43.6	4.08	11,450	2,810	1,270	656	1.16	.58	
141	467	505	233	18	55.2	52.5	4.08	11,150	2,740	2,200	267	9.20	.63	
Average	394	459	214	22	40.6	41.3	4.08	10,690	2,620	1,670	475.8	4.30	.57	
102	352	356	177	16	24.7	24.6	4.02	13,440	3,340	2,110	933	2.47	....	Green. Kept in damp box 4 months, as explained above. Nos. 102 and 112, etc., were cut from opposite ends of the strips from which the rest of the series were cut.
109	....	366	182	16	26.1	25.6	4.06	12,870	3,170	2,340	722	3.81	.50	
112	385	381	190	16	25.5	25.4	4.04	12,000	2,970	2,230	345	7.24	....	
199	390	379	189	17	25.7	25.7	4.05	12,540	3,100	2,340	500	5.57	.49	
122	380	385	192	27	26.2	26.3	4.05	14,150	3,500	2,840	315	1.28	....	
129	388	386	191	....	26.2	26.1	4.02	14,220	3,540	2,660	364	9.77	.49	
132	377	377	187	24	25.5	25.7	4.06	13,560	3,340	2,340	296	9.36	....	
139	395	396	198	23	25.6	25.7	4.04	14,680	3,630	3,170	348	14.40	.50	
142	509	430	217	19	44.5	55.5	4.01	12,680	3,160	2,620	540	6.40	....	
149	....	....	190	14	25.8	....	4.07	13,000	3,190	1,470	304	4.07	.48	
Average	397	384	191	19	27.6	28.9	4.04	13,314	3,294	2,412	467	7.58	.491	
103	355	312	156	17	10.5	10.5	3.78	22,100	5,850	4,760	1,024	11.1	....	Air-dried. Stood in room for 21 days.
113	385	329	165	16	10.8	10.6	3.83	21,670	5,650	4,700	494	24.1	....	
123	385	338	170	26	10.9	10.7	3.82	23,470	6,150	5,500	873	17.4	....	
133	380	328	163	30	10.7	10.3	3.77	26,000	6,900	6,100	1,138	16.8	....	
143	417	323	162	19	11.1	10.5	3.77	22,590	5,990	5,310	1,031	13.7	....	
Average	384	326	163	22	10.8	10.5	3.79	23,160	6,108	5,274	912	16.6	....	

104	372	319	159	14	8.1	7.7	3.77	27,650	7,340	5,040	1,060	12.0	....	Partly kiln-dry. Dried in kiln with steam 15 days; low temperature at first, then raised to 130° F.; then dry heat of 100° to 120° F. for 10 days.
114	396	323	161	16	7.8	8.1	3.78	26,2[illegible]0	6,940	4,640	974	11.2	....	
124	378	326	164	21	8.2	....	3.69	29,480	8,000	7,050	1,195	20.9	....	
134	387	325	162	25	8.4	8.4	3.70	30,060	8,130	6,630	1,167	17.7	....	
144	408	318	157	16	7.8	7.8	3.72	29,480	7,930	6,890	1,069	22.5	....	
Average	388	322	161	18	8.1	8.0	3.73	28,570	7,668	6,050	1,093	16.9	....	
106	364	304	152	17	6.0	5.7	3.71	30,490	8,220	5,940	1,327	13.3	....	Partly kiln-dry. Same as last, except dry heat for 13 days.
116	344	323	157	17	6.3	5.9	3.70	29,070	7,870	5,810	1,238	13.8	....	
126	402	334	165	30	6.7	6.4	3.72	32,700	8,800	7,260	1,240	19.4	....	
136	384	317	159	29	6.0	6.3	3.70	32,700	8,840	6,630	1,256	17.7	....	
146	412	308	153	....	5.8	6.0	3.73	32,970	8,840	7,300	1,410	18.8	....	
Average	381	317	157	23	6.1	5.9	3.71	31,580	8,514	6,588	1,294	16.6	....	
			5¾ inches long.											
107	384	317	157	14	5.2	5.4	3.80	29,860	7,860	5,270	1,315	11.0	.44	Kiln-dry. Same as No. 104, except dry heat for 39 days.
117	409	319	159	18	5.2	5.4	3.76	30,000	7,980	4,650	1,205	9.1	.45	
127	382	317	158	27	5.0	5.1	3.69	33,000	8,950	7,460	1,320	21.1	.46	
137	380	312	156	26	4.0	5.1	3.67	32,250	8,790	7,090	1,195	21.3	.45	
147	382	317	157	23	5.2	5.2	3.75	33,820	9,020	6,140	1,390	13.6	.44	
Average	387	316	156	22	4.9	5.2	3.73	31,780	8,520	6,122	1,285	15.2	.45	
			6 inches long.											
107	363	289	145	16	1.1	1.3	3.61	36,000	9,980	6,940	1,410	17.0	.41	Oven-dry. Same as No. 104, except dry heat for 19 days, and then placed in oven during day time at 208° F. for 8 days. Cooled in desiccator before testing.
117	380	302	145	19	.9	1.3	3.60	34,200	9,500	6,390	1,312	15.5	.43	
127	375	300	150	26	1.3	.8	3.61	37,000	10,250	6,100	1,630	11.4	.42	
137	407	317	158	26	1.0	1.3	3.58	40,000	11,180	7,820	1,640	18.9	.45	
147	385	296	149	16	1.3	1.0	3.60	36,520	10,140	6,670	1,435	15.6	.42	
Average	382	301	149	21	1.1	1.1	3.60	36,740	10,210	6,784	1,486	15.7	.426	

TABLE 3.—*Spruce. Compression parallel to grain. Lot of 1903. Size, 2 by 2 by 6 inches*—Continued.

REABSORPTION.

No. of test piece.	Weight when cut (12 inches long).	Weight at test. 12 inches long.	Weight at test. $5\frac{3}{4}$ inches long.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. Elsewhere, disk *c*.	Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Elastic resilience per cubic inch.	Weight when kiln dry, (8 inches long).	Moisture, disk *x*. Outside.	Moisture, disk *x*. Inside.	Condition and treatment.
1	2	3	4	5	6	7	9	10	11	12	13	14	16	17	18	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Sq. inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 lbs.*	*Inch-lbs.*	*Grams.*	*Per cent.*	*Per cent.*	
105	356	422	178	17	30.9	30.0	4.04	9,550	2,360	1,610	570	2.3	298	29.5	30.4	Resoaked. Kiln-dried 2 months; with steam 15 days, dry heat 45 days; then stood in room 14 days, then soaked in water 30 days. (Ends only were water soaked, which were cut off before testing.)
115	420	477	209	20	46.8	50.0	4.03	9,030	2,240	1,360	650	1.4	309	......	......	
125	385	451	193	30	31.4	29.8	4.03	11,000	2,730	1,240	717	1.1	322	30.5	29.1	
135	380	456	190	34	33.5	31.8	4.05	10,100	2,500	1,330	710	1.3	314	......	......	
145	420	489	209	......	47.0	44.5	3.99	10,000	2,510	1,630	650	2.0	309	......	......	
Average	392	459	196	25	37.9	37.2	4.03	9,936	2,468	1,434	659	1.6	310	30.0	29.8	
108	371	....	185	17	32.1	....	4.12	9,700	2,350	1,210	563	1.3	310	......	......	Reabsorbed. Kiln-dried, as No. 105, then stood in room 52 days, subjected to cool condensed steam 2 days, and kept in damp box 40 days.
118	414	....	191	18	34.7	....	4.02	10,000	2,480	1,370	516	1.9	312	......	......	
128	378	....	187	20	31.3	....	4.07	10,325	2,530	1,720	639	1.5	315	......	......	
138	389	....	186	28	29.2	....	4.06	11,150	2,750	1,720	688	2.2	317	......	......	
148	404	....	189	16	38.5	....	4.09	10,425	2,550	1,590	704	1.8	311	......	......	
Average	391	....	188	20	33.2	....	4.07	10,320	2,532	1,522	622	1.7	313	......	......	

TABLE 4.—*Chestnut. Compression parallel to grain. Size, 2 by 2 by 5¾ inches.*

Three-inch planks procured May 18, 1904, freshly sawed in vicinity of New Haven. Specimens were prepared about May 24 and treated in 8-inch lengths unless otherwise noted.

No. of test piece.	Weight when cut (8 inches long).	Weight at test.		Rings per inch.	Moisture.		Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Dry specific gravity.	Moisture, disk *x*.		Condition and treatment.
		8 inches long.	5¾ inches long.		At break, disk *a*.	Elsewhere, disk *c*.							Outside.	Inside.	
1	2	3	4	5	6	7	9	10	11	12	13	15	16	17	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Pounds.*	*Pounds.*	*Lbs.*	*1,000 lbs.*		*Per cent.*	*Per cent.*	
101	475	517	365	8	150	152	4.10	12,250	2,990	2,440	702	....	....	....	Soaked. Soaked in water for 21 days, beginning May 24 (outdoors).
111	457	517	364	4	140	137	4.06	12,600	3,100	2,460	745	....	....	....	
121	565	585	415	5	121	118	4.00	12,900	3,230	2,500	822	....	....	....	
131	462	505	355	8	138	....	4.06	14,190	3,500	2,710	859	....	142	156	
141	497	542	382	5	140	....	4.06	13,900	3,430	2,590	853	....	148	141	
151	526	555	395	4	131	....	4.02	11,825	2,940	2,240	714	....	....	....	
161	562	580	413	5	131	....	4.03	14,365	3,560	2,480	952	....	....	....	
171	490	532	377	7	142	....	4.02	13,300	3,310	2,480	765	....	....	....	
181	508	542	387	10	135	....	3.98	11,140	2,800	2,260	....	....	147	133	
191	475	522	370	6	140	....	4.00	11,380	2,850	2,250	719	....	140	137	
Average	502	540	382	6	137	136	4.03	12,785	3,171	2,441	792	....	144	142	
102	482	(482)	347	8	143	139	4.00	11,280	2,820	2,500	882	.92	....	....	Green. Tested after being kept damp for 2 days.
112	470	(470)	345	3	119	123	4.02	11,700	2,910	2,480	804	91	....	....	
122	567	(567)	406	5	117	116	3.97	12,380	3,120	2,520	796	1.08	....	....	
132	467	(467)	335	9	121	122	4.03	12,720	3,160	2,730	927	.88	....	....	
142	445	(445)	320	4	115	116	3.91	12,180	3,120	2,820	835	.87	....	....	
152	535	(535)	388	4	125	126	3.99	11,390	2,860	2,250	668	1.03	....	....	
162	562	(562)	400	4	120	120	3.97	12,920	3,260	2,780	724	1.07	....	....	
172	493	(493)	356	7	133	132	3.99	11,840	2,970	2,510	747	.95	....	....	
182	515	(515)	374	9	127	128	3.98	10,060	2,530	2,260	....	1.00	....	....	
192	505	(505)	365	6	130	131	4.02	11,670	2,900	2,230	714	.96	....	....	
Average	504	(504)	364	6	125	125	3.99	11,814	2,965	2,508	789	.967	....	....	

TABLE 4.—*Chestnut. Compression parallel to grain. Size, 2 by 2 by 5¼ inches*—Continued.

No. of test piece.	Weight when cut (8 inches long).	Weight at test.		Rings per inch.	Moisture.		Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Dry specific gravity.	Moisture, disk *x*.		Condition and treatment.
		8 inches long.	5¼ inches long.		At break, disk *a*.	Elsewhere, disk *c*.							Outside.	Inside.	
1	2	3	4	5	6	7	9	10	11	12	13	15	16	17	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Pounds.*	*Pounds.*	*Lbs.*	*1,000 lbs.*		*Per cent.*	*Per cent.*	
103	492	....	175	9	19.9	....	3.90	12,790	3,280	2,570	737	....	....	....	Partly dry. Kiln-dried with steam at 130° to 140° F. and humidity of 75 to 80 per cent, but drier at night, for 21 days, then trimmed to 5¼-inch lengths and put in damp box for 48 days. (The wet spot in the center had disappeared.)
113	478	....	184	4	19.1	....	3.92	14,600	3,730	3,060	735	....	....	....	
123	560	....	220	4	20.7	....	3.88	14,475	3,730	2,840	773	....	....	....	
133	467	....	180	8	22.4	....	3.90	14,215	3,650	2,820	758	....	....	....	
143	452	....	180	4	20.3	....	3.88	13,200	3,400	2,190	690	....	....	....	
153	532	....	210	4	21.8	....	3.84	14,100	3,670	2,870	805	....	....	....	
163	557	....	218	5	24.1	....	3.84	14,730	3,840	3,000	750	....	....	....	
173	492	....	185	6	21.1	....	3.90	13,240	3,400	2,300	738	....	....	....	
183	520	....	204	8	26.8	....	3.80	11,555	3,040	2,630	561	....	....	....	
193	507	....	212	6	21.1	....	3.91	13,300	3,400	3,580	870	....	....	....	
Average	506	....	197	6	21.7	....	3.88	13,620	3,514	2,786	742	....	....	....	
106	470	232	160	9	12.5	....	3.81	18,460	4,850	3,420	1,160	....	9.8	14.5	Partly kiln-dried. Kiln-dried, as last, with steam for 23 days—15 days 8-inch length stood on end, laid horizontally 3 days, then trimmed to 5¼ inches for the last 5 days.
116	430	242	167	4	9.7	....	3.77	23,300	6,190	4,240	1,023	....	8.7	10.7	
126	540	280	193	4	13.1	11.0	3.78	20,000	5,290	3,180	940	....	10.7	16.8	
136	445	230	162	8	12.2	10.8	3.79	22,135	5,840	3,830	1,012	....	10.6	13.5	
146	485	249	173	4	13.8	12.0	3.84	20,920	5,450	3,650	1,025	....	....	....	
156	512	267	185	3	11.0	....	3.78	19,950	5,280	....	707	....	10.4	12.1	
166	575	297	207	5	14.9	14.7	3.82	18,180	4,760	3,140	1,132	....	....	....	
176	460	238	164	8	11.6	10.8	3.83	19,735	5,150	3,130	826	....	....	....	
186	525	294	200	5	20.2	12.8	3.74	14,525	3,890	2,410	725	....	....	....	
196	465	234	165	6	11.2	9.4	3.82	21,320	5,580	3,670	876	....	....	....	
Average	491	256	177	6	13.0	11.6	3.80	19,852	5,228	3,410	943	....	10.4	13.5	

104	457	....	144	10	2.7	....	3.66	32,360	8,850	6,840	1,113	.42	....	....	Kiln-dry. Kiln-dried with steam as No. 103 for 21 days, then dry heat for 11 days at 140° F.
114	440	....	156	4	2.3	....	3.57	32,900	9,220	6,730	1,330	.51	2.4	2.6	
124	522	....	186	4	2.8	....	3.60	34,000	9,450	6,950	1,330	.55	....	....	
134	468	....	150	9	2.5	....	3.57	34,400	9,640	6,730	1,200	.45	2.3	2.7	
144	460	....	151	4	2.7	....	3.69	33,760	9,150	7,050	1,198	.43	....	....	
154	508	....	174	4	2.5	....	3.53	30,000	8,500	4,820	930	.52	2.5	2.6	
164	557	....	185	5	3.1	....	3.62	35,220	9,750	6,640	1,220	.54	....	....	
174	490	....	157	6	2.3	....	3.64	30,570	8,400	5,230	918	.46	....	....	
184	....	....	....	9	2.6	....	Split.	....	....	....	....	....	....	....	
194	502	....	160	6	2.4	....	3.55	31,360	8,840	6,770	1,131	.48	....	....	
Average	489	....	162	6	2.6	....	3.60	32,730	9,089	6,418	1,152	.484	2.4	2.6	
105	462	....	145	9	1.6	1.6	3.68	34,260	9,330	7,080	1,200	.42	....	....	Oven-dry. Kiln-dried, as last, for 25 days, then trimmed to 5½-inch lengths and dried in oven during day at 208° F., and kiln at night for 4 days. The last five were subjected to a vacuum of 26 inches for two days of this time, 8 hours each. Cooled in desiccator before testing.
115	437	....	159	5	1.6	1.4	3.66	37,690	10,300	7,650	1,288	.46	....	....	
125	532	....	179	4	1.5	1.4	3.65	35,690	9,780	6,980	1,110	.52	....	....	
135	465	....	149	9	1.4	1.4	3.63	35,850	9,880	6,610	1,238	.44	....	....	
145	465	....	153	4	1.4	1.3	3.68	34,000	9,250	6,800	1,250	.44	....	....	
155	512	....	169	5	.4	....	3.64	29,900	8,220	4,950	790	.49	....	....	
165	559	....	180	7	.3	....	3.61	33,000	9,140	7,200	1,067	.53	....	....	
175	465	....	150	8	.4	....	3.67	30,140	8,210	4,640	964	.53	....	....	
185	465	....	170	6	....	....	....	....	....	4,470	....	.50	....	....	
195	488	....	152	3	.4	....	3.65	34,900	9,570	6,580	1,050	.44	....	....	
Average	485	....	161	6	1.0	....	3.65	33,937	9,298	6,296	1,106	.467	....	....	

TABLE 4.—*Chestnut. Compression parallel to grain. Size, 2 by 2 by 5¼ inches*—Continued.

REABSORPTION.

No. of test piece.	Weight when cut (8 inches long).	Weight at test.		Rings per inch.	Moisture.		Area at break.	Total crushing load.	Crushing strength per square inch, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, *Ec*.	Weight when kiln dry, (8 inches long).	Condition and treatment.
		8 inches long.	5¼ inches long.		At break, disk *a*.	Elsewhere, disk c.							
1	2	3	4	5	6	7	9	10	11	12	13	15	
	Grams.	*Grams.*	*Grams.*		*Per cent.*	*Per cent.*	*Square inches.*	*Pounds.*	*Pounds.*	*Lbs.*	*1,000 lbs.*	*Grams.*	
107	480	....	185	8	21.6	....	3.88	11,510	2,970	2,060	579	222	Reabsorbed. Kiln-dried, as No. 103, for 35 days, then cut to 5¼-inch lengths and put in damp box for 32 days.
117	426	....	180	5	20.4	....	3.88	9,975	2,570	1,550	660	220	
127	540	....	204	4	22.3	....	3.84	11,600	3,020	2,080	577	245	
137	460	....	199	9	20.0	....	3.88	13,280	3,430	2,840	741	216	
147	507	....	198	4	22.7	....	3.92	12,100	3,090	2,550	764	237	
157	512	....	204	3	20.5	....	3.85	10,300	2,680	2,080	376	241	
167	560	....	207	5	21.5	....	3.86	14,000	3,630	2,590	785	250	
177	462	....	177	8	21.3	....	3.88	10,800	2,790	1,550	662	214	
187	530	....	207	6	23.2	....	3.82	9,615	2,520	1,830	407	248	
197	455	....	184	7	21.6	....	3.86	11,465	2,970	1,940	668	223	
Average	493	....	195	6	21.5	....	3.87	11,464	2,967	2,107	622	252	
108	470	365	245	8	58.8	....	3.94	9,450	2,400	1,900	510	214	Resoaked. Kiln-dried, as last, for 35 days, then soaked in water for 33 days.
118	449	375	245	4	47.4	....	4.03	9,650	2,390	1,980	357	227	
128	555	440	300	6	49.6	....	4.02	10,900	2,710	2,110	524	275	
138	460	365	230	8	63.0	....	3.98	10,615	2,670	2,260	498	216	
148	435	358	....	4	52.5	....	3.89	10,400	2,670	2,180	616	220	
158	520	395	255	4	53.2	....	3.92	9,000	2,300	1,660	375	242	
168	555	415	285	4	96.0	....	3.93	10,370	2,640	1,910	457	267	
178	480	358	....	7	49.5	....	4.02	10,825	2,690	2,240	525	220	
188	502	368	227	6	52.0	....	3.91	8,925	2,280	1,790	367	230	
198	472	362	240	11	43.6	....	4.00	8,835	2,200	1,750	377	220	
Average	490	380	253	6	56.6	....	3.96	9,897	2,495	1,978	461	233	

BENDING.

(Tables 5, 6, 7.)

All the bending tests were made upon the Olsen machine. An attachment for this purpose was constructed, consisting of two 5-inch steel I-beams, bolted together side by side, upon which slide two cast-iron blocks, 6 inches high, serving for the end supports of the bending test specimen. These supports may be set and clamped fast for any desired span, and have a rounded horizontal edge on top at right angles to the beam. The radius of the rounded edge is about three-eighths inch. In making the test a flat steel plate about 1 inch wide and three-eighths inch thick was placed between either edge and the specimen so as to prevent undue cutting into the fiber by the edge. This steel beam was laid across the platform of the machine. The bending force was applied at the middle by a similar horizontal edge, attached to the crosshead; and beneath this was placed a block of hard maple, the lower surface of which is curved in the direction along the beam with a radius of 6 inches, in order to prevent the edge from crushing into the fibers of the test piece.

The test specimens had been planed to 2 by 2 inches when green. The longleaf pine had been cut 42 inches long, and the others 40 inches. The span in all cases was 3 feet. The machine was always balanced before applying the initial load.

The grain for these beams was chosen, as far as possible, so that the rings, in the cross section, ran diagonally, as it was found that the pieces dried much better when cut in this manner and did not check, while those cut parallel to the rings often checked on the tangential surfaces in drying. It was found from special tests that it made no appreciable difference in the strength whether the rings were horizontal or diagonal. (See tests numbered with a subscript, Tables 6 and 7.)

As the specimens had been cut square when green, it followed that in drying the cross section became somewhat diamond-shaped, and sometimes the beams became warped. It is thought that this slight distortion of the dimensions does not appreciably affect the results, since the difference between the true vertical height of the beam and the slanting height of the distorted section is less than the smallest measurement used, and since the warped condition disappears as soon as the initial load of about 200 pounds is applied.

The exact height and width of each specimen was measured at the center to the nearest hundredth inch before testing.

The method of measuring deflections was such that any compression of the supports or cutting in of the three edges did not affect the readings. A fine wire was stretched along the side of the beam from a

small nail at either end, driven in directly above the support and on the axis of the beam, and kept taut by means of a rubber band on one end. A steel scale graduated to hundredths of an inch was fastened vertically at the center of the beam behind the wire. It is held in place by two thumb tacks through holes in the scale, pressed into the wood. Care was taken not to place the tacks near the top or bottom of the beam lest they should affect the strength. The readings were taken where the wire cross the scale, by means of a telescope, about 10 feet distant and approximately on a level with the wire. This avoided error due to parallax, since the point of view was always the same, and enabled one to read with perfect assurance up to the point of failure.

Deflections were reported every 100 or 200 pounds, according to the strength of the specimen, up to beyond the maximum point, which was also noted, the readings being to the nearest hundredth of an inch. The load was continuously applied and the rate of deflection was ten times that of the compression tests, or about 0.1 inch per minute. The time was taken at start and finish, and occasionally at intermediate points.

As explained on page 20, this caused a variable rate of fiber stress depending upon the characteristics of the specimens. In general, the rate of fiber stress of the extreme fibers per square inch per minute is summed up in the following table:

Species.	Green.			Dry.		
	Average.	Maximum.	Minimun.	Average.	Maximum.	Minimum.
Longleaf pine	1,998	2,570	1,570	2,230	2,760	1,840
Spruce	1,266	1,600	915	1,652	1,770	1,430
Chestnut	1,080	1,340	730	1,515	1,820	1,220

Failure usually occurs, except in the extremely dry specimens, by compression parallel to grain of the fibers on top of the beam, showing at first as a fine, wavy line across the upper surface at the middle, and gradually extending downwards toward the axis. (See Pl. I, fig. 2.) Unlike the failure in the compression tests, this failure is usually visible some time before the maximum load is reached. In fact, it begins shortly after the elastic limit has been passed. Finally the beam snaps across the bottom and sometimes breaks entirely in two. The drier the material the more apt it is to snap across the bottom by tension along the grain before much compression occurs on top, and when very dry no compression whatever occurs, the failure being entirely by tension on the under side. This tension failure is usually combined with a more or less irregular splitting of the fibers lengthwise, often into the middle of the beam and halfway to the support. The dry beams often fail suddenly without any previous warning, while the

load is still increasing, so that in such cases there is no true maximum point. Occasionally a dry beam will snap completely in two so suddenly that the ends fly up in the air. The chestnut shows this sudden failure when dry, the longleaf pine shows it much less, and the spruce takes an intermediate place.

The wet or green specimens, on the other hand, generally do not fail on the bottom at all, and have a true maximum point. The maximum point of green beams is even much more gradual than that of the green compression tests, and the falling of the load is very slow. The

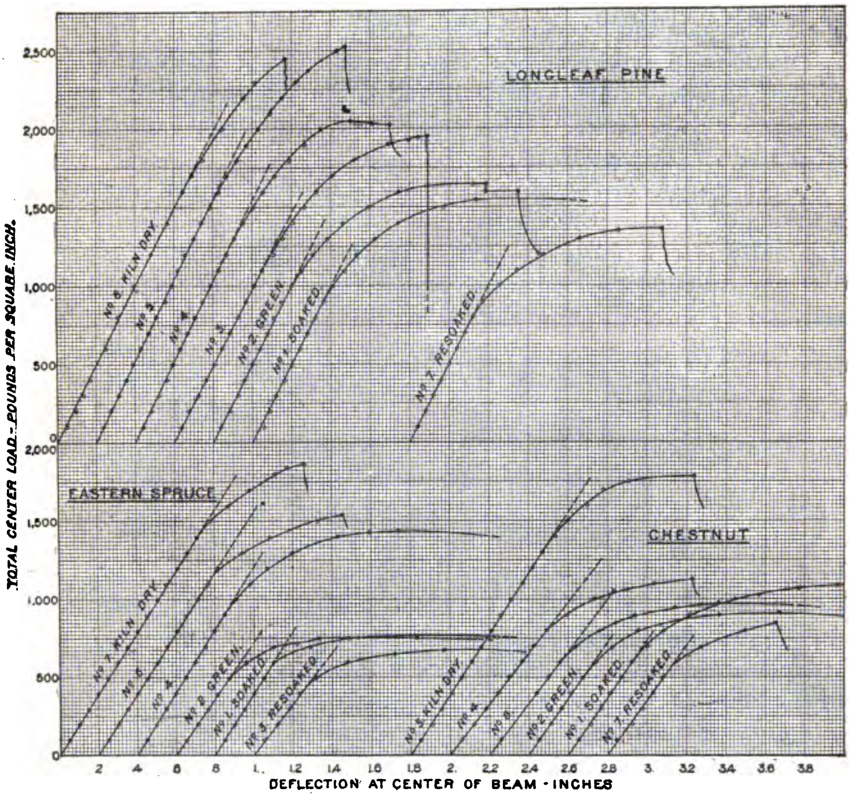

FIG. 2.—Stress-strain diagrams of single series of bending tests. (See Tables 5, 6, and 7.)

load will often remain constant near the maximum point for several minutes. This is especially true with the wet chestnut, some of the beams deflecting over 4 inches without breaking, the maximum point, of course, having been passed. The difference in the method of failure between the dry and the wet beams is shown in Pl I, fig. 2.

It is a curious and significant fact that the resoaked beams, after having been once kiln-dried, do not as a rule fail like the original green ones, but snap on the bottom by tension, as do the dry ones, showing

no compression on top. The kiln drying seems to have permanently increased the brittleness of the wood.

What has been said of the elastic limit in compression applies also to bending, except that it is even less definitely located than it is in the compression. All the results for the bending tests have been derived from the stress and strain diagram, as was done for the compression tests. A straight line is drawn tangent to the most regular straight part of the diagram, and is extended downward to the zero load line. The modulus of elasticity and the elastic limit are derived from this line, thus eliminating small variables and irregularities at the initial part of the test. (Fig. 2.)

The effect of moisture upon the stress and strain diagrams is similar to that of the compression tests, and is illustrated in fig. 2, by three of the bending series. The modulus of elasticity is more irregular than that in compression.[a]

A compression piece was cut and tested from all of the longleaf pine beams and from representative ones from the spruce and chestnut, and the values worked up just as in the regular compression tests. The results compared with the equivalent values of the beam from which they were cut show the comparison of these unit values for the three species, for the same piece of wood, under compression and under bending stresses at the different degrees of moisture. An examination of columns 17 and 18 as compared with columns 12 and 14, Tables 5 and 6, shows that the bending values are invariably much greater than the corresponding compression values. This is partly due to the greater strength and elasticity of wood under tensile stress. It appears that the fiber stress at the elastic limit in bending corresponds closely to the ultimate strength of the wood in compression.[b] (See Table 17, p. 90, also fig. 13, the dotted curve for longleaf pine, and fig. 16 for spruce.)

Moisture disks were cut from each beam, as in compression tests, disk *a* being at the center and disk *c* at about 9 inches from the center, and disks *x* and *b* adjacent to either one of the others. The piece for the compression test was taken as near the center as possible without encountering any of the broken portion. The compression piece was tested the same day as the beam, so as to have the same moisture condition.

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[a] Although in these diagrams, fig. 2, the curves of the dry beams are little or no steeper than the wet ones, it should be considered that the depths of former beams are less than the latter, due to shrinkage in drying, and when this circumstance is considered the stiffness of the dry beams is found to exceed the wet ones. See formula for modulus of elasticity, Appendix.

[b] See article by Mr. S. T. Neely, in Circular 18, Bureau of Forestry, 1898.

TABLE 5.—*Longleaf pine, bending tests. Size, 2 by 2 by 42 inches; span, 36 inches.*

Regarding lumber, see note for longleaf pine compression tests, Table 1. Specimens prepared July 16 to 20, 1903, and kept damp until treated.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture— At break, disk *a*.	Moisture— At ¼ span, disk *c*.	Dimensions at center. Height.	Dimensions at center. Width.	Maximum center load.	Modulus of rupture, *R*.	Stress at elastic limit, *f*.	Modulus of elasticity, *E*.	Specific gravity.	Elastic resilience per cubic inch.	Compression piece cut from beam. Crushing strength per square inch, *c*.	Compression piece cut from beam. Modulus of elasticity, *Ec*.	Compression piece cut from beam. Elastic resilience per cubic inch.	Condition and treatment.
1	2	3	4	5	6	9	10	11	12	13	14	15	16	17	18	19	
	Grams.	*Grams.*	*Grams*	*Per ct.*	*Per ct.*	*Inches.*	*Inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 pounds.*		*Inch-lbs.*	*Lbs.*	*1,000 lbs.*	*Inch-lbs.*	
1	....	2,105	23	63.3	....	2.00	2.01	1,000	6,716	4,040	1,296	......	0.71	3,300	......	......	Soaked. Immersed in tank outdoors July 31, 1903, where they remained most of the time until March 11, 1904, incased in solid ice during the cold weather.
11	2,260	2,650	14	42.0	....	2.01	2.01	1,550	10,310	4,980	2,216	......	.65	5,320	1,420	3.62	
31	1,832	2,280	24	48.3	....	2.00	2.01	1,035	6,951	4,760	1,707	......	.76	4,420	1,000	6.02	
41	1,975	2,460	11	51.7	....	2.01	2.01	1,530	10,170	4,780	1,958	......	.64	4,950	1,084	6.04	
51	2,130	2,575	17	46.4	....	2.01	2.01	1,550	10,310	6,040	2,306	......	.87	5,350	1,059	5.51	
Average	2,049	2,414	18	50.3	....	2.01	2.01	1,333	8,891	4,920	1,896	......	.73	4,668	1,141	5.30	
2	....	1,669	28	21.5	21.6	2.00	2.00	1,125	7,256	6,750	1,429	0.61	1.76	4,380	1,034	5.58	Green. Kept damp until tested (2 weeks).
12	....	2,218	13	22.3	21.4	2.00	2.00	1,400	9,450	6,080	2,209	.81	1.15	5,220	1,500	4.29	
32	....	1,852	15	23.1	23.1	2.00	2.00	1,425	9,619	6,080	1,919	.67	1.28	5,000	1,364	5.50	
42	....	2,118	10	24.4	23.9	2.00	2.00	1,650	11,140	6,080	1,970	.71	1.07	5,850	1,035	12.60	
52	....	1,970	11	23.6	22.6	2.00	2.00	1,460	9,855	4,730	1,402	.72	1.04	5,050	1,035	6.38	
Average	....	1,965	15	23.0	22.5	2.00	2.00	1,412	9,464	5,944	1,786	.69	1.26	5,100	1,194	6.87	
3	....	1,441	25	13.2	13.3	1.97	1.96	1,180	8,377	6,560	1,469	......	1.77	5,700	1,020	8.52	Partly air-dry. Dried in kiln with steam about 80° F. for 8 days and about 115° for 2 days, then placed in room 7 days.
13	....	2,177	25	15.6	14.8	1.97	1.98	1,500	10,540	7,720	2,141	......	1.51	6,500	1,173	4.52	
33	....	1,788	15	12.4	11.9	1.96	1.96	2,025	14,520	6,460	2,310	......	1.24	7,500	1,550	6.47	
43	....	1,924	8	14.5	14.2	1.95	1.95	1,955	14,230	7,430	1,968	......	1.80	6,570	1,345	7.22	
53	....	1,800	14	14.2	14.6	1.96	1.94	1,740	12,600	6,450	1,663	......	1.39	6,060	1,020	8.87	
Average	....	1,826	17	14.0	13.8	1.96	1.96	1,680	12,053	6,924	1,910	......	1.54	6,466	1,222	7.12	

TABLE 5.—*Longleaf pine, bending tests. Size, 2 by 2 by 42 inches; span, 36 inches*—Continued.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture— At break, disk *a*.	Moisture— At ½ span, disk *c*.	Dimensions at center. Height.	Dimensions at center. Width.	Maximum center load.	Modulus of rupture, *R*.	Stress at elastic limit, *f*.	Modulus of elasticity, *E*.	Specific gravity.	Elastic resilience per cubic inch.	Compression piece cut from beam. Crushing strength per square inch, *c*.	Compression piece cut from beam. Modulus of elasticity, *E*.	Compression piece cut from beam. Elastic resilience per cubic inch.	Condition and treatment.
1	2	3	4	5	6	9	10	11	12	13	14	15	16	17	18	19	
	Grams.	*Grams.*	*Grams*	*Per ct.*	*Per ct.*	*Inches.*	*Inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 pounds.*		*Inch-lbs.*	*Lbs.*	*1,000 lbs.*	*Inch-lbs.*	
4		1,488		11.0	11.0	1.96	1.95	1,475	10,630	7,210	1,589		2.14	6,320	1,005	4.89	Partly kiln-dried. Dried in kiln with steam 13 to 14 days, cool as above for first 8 days, then at about 115° F., then placed in room 5 days.
14		1,917		12.8	12.1	1.95	1.97	2,000	14,420	7,210	2,101		1.26	8,300	1,491	10.10	
34		1,636	13	10.3	10.3	1.95	1.95	1,950	13,880	10,780	2,069		3.48	(8,500)	1,595	7.37	
44		1,882	16	11.8	11.5	1.94	1.94	2,050	15,160	7,400	2,225		1.27	7,740	1,595	8.88	
54		1,764	13	11.7	11.9	1.95	1.92	1,700	12,570	6,660	1,755		1.11	6,470	1,230	7.71	
Average		1,737	14	11.5	11.4	1.95	1.95	1,835	13,332	7,852	1,948		1.85	7,466	1,383	7.79	
5	1,718	1,477	25	10.2	9.8	1.96	1.93	1,600	11,650	7,280	1,784		1.04	6,780	1,137	12.40	Partly kiln-dried. Dried in kiln 21 days, with steam 14 days, as last, then dry heat of 115° to 120° F. for 7 days, and finally placed in room for 7 days.
15	2,204	1,918	25	10.5	10.4	1.94	1.95	1,900	13,910	7,360	1,895		1.56				
35	2,020	1,744	15	9.7	8.5	1.91	1.92	2,020	15,510	(8,480)	2,642		1.45	10,270	1,760	16.10	
45	1,987	1,722	15	8.4	8.3	1.91	1.91	2,525	19,530	10,850	2,307		2.48	9,890	1,433	14.75	
55	2,137	1,845	12	9.6	9.0	1.94	1.91	2,125	15,960	10,510	2,144		2.80	9,000	1,524	8.67	
Average	2,013	1,741	18	9.7	9.2	1.93	1.92	2,034	15,324	8,896	2,154		1.87	8,985	1,464	12.98	
6	1,692	1,342	22	5.6	5.8	1.94	1.93	2,050	15,240	6,690	2,018	.52	1.27	8,980	1,355	18.50	Kiln-dry. Dried in kiln as No. 5 for 45 days.
16	2,244	1,865	12	6.0	6.2	1.90	1.91	2,650	20,360	15,650	2,872	.75	5.21	11,460	2,432	21.10	
36	1,800	1,561	16	6.0	6.2	1.93	1.93	2,375	17,650	12,010	2,212	.61	3.25	10,960	1,910	16.00	
46	2,112	1,803		6.4	6.3	1.92	1.90	2,450	18,940	10,800	2,289	.72	3.05	10,850	1,856	15.90	
56	2,095	1,800		6.9	7.1	1.89	1.92	2,400	18,950	12,600	2,493	.72	2.13	12,300	2,139	17.40	
Average	1,989	1,674	16	6.2	6.3	1.92	1.92	2,385	18,228	11,550	2,377	.66	2.98	10,910	1,938	17.78	

REABSORPTION.

7	1,617	1,852	21	37.5	37.5	2.01	2.01	995	6,617	3,520	1,263	......	1.14	3,090	644	4.82	Resoaked. Kiln-dried as No. 6 for 45 days, then immersed in tank as No. 1 until April 27, 1904—about 7 months.
37	2,048	2,255	12	34.0	28.7	2.00	2.01	1,415	9,504	3,800	1,685	......	.97	5,000	1,061	5.84	
47	2,208	2,400	9	30.1	27.2	2.01	1.99	1,360	9,105	5,760	1,968	......	2.09	4,370	1,060	6.53	
57	1,960	2,203	11	35.5	35.5	2.01	2.01	1,425	9,470	5,500	1,762	......	1.89	4,410	1,200	5.08	
Average	1,958	2,178	14	34.3	32.2	2.01	2.01	1,299	8,674	4,645	1,669	......	1.52	4,218	991	5.57	

SERIES ABNORMALLY RESINOUS AND NOT AVERAGED WITH THE REST.

61	2,672	2,850	30	24.3	....	2.00	2.00	1,450	9,787	5,000	1,869	......	0.74	4,830	1,080	8.18	The treatment which these received was the same as the corresponding sets above. The specimens varied somewhat and the results are irregular. Both series were very resinous.
22	....	1,880	10	22.6	22.1	2.00	2.00	1,475	9,956	6,080	1,995	0.68	1.28	5,480	1,500	6.38	
62	....	2,570	24	21.9	21.4	2.00	2.00	1,600	10,800	5,670	1,402	.93	1.50	5,680	1,000	6.71	
23	....	1,672	13	14.9	12.9	1.98	1.98	1,900	13,230	6,960	2,108	......	2.10	5,970	1,225	8.03	
63	....	2,500	24	15.8	15.4	1.97	1.97	2,020	14,270	7,750	2,151	......	1.96	7,390	1,417	11.80	
24	....	1,670	13	14.1	8.6	1.97	1.97	2,260	15,960	8,480	2,213	......	1.82	8,370	1,693	4.74	
64	....	2,982	25	14.3	14.2	1.96	1.96	1,525	10,900	6,460	1,882	......	1.21	5,650	1,345	7.13	
25	2,000	1,737	20	8.2	8.0	1.91	1.90	2,950	22,980	9,350	2,753	......	1.52	10,900	1,627	2.14	
65	3,116	2,972	25	13.3	13.4	1.96	1.95	1,720	12,400	6,500	2,228	......	1.22	5,470	1,353	6.81	
26	1,986	1,883	15	5.0	5.2	1.94	1.94	2,325	17,150	9,610	2,058	.73	2.72	11,550	1,816	2.19	
66	2,705	2,369	22	10.4	10.1	1.93	1.93	2,625	19,680	13,520	2,802	.92	3.20	12,030	2,310	11.80	
67	2,878	2,801	29	18.0	18.8	2.00	1.99	1,740	11,810	8,150	1,975	......	3.69	5,880	1,131	11.20	

TABLE 6.—*Spruce, bending tests. Size, 2 by 2 by 40 inches Span, 36 inches.*

Regarding lumber from which specimens were cut see 1904, Table 2.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. At ½ span, disk *c*.	Moisture. Disk *x*. Out-side.	Moisture. Disk *x*. In-side.	Dimensions at center. Height.	Dimensions at center. Width.	Maxi-mum center load.	Modu-lus of rup-ture, *R*.	Stress at elastic limit, *f*.	Modulus of elas-ticity, *E*.	Specific grav-ity.	Compression piece cut from beam. Crushing strength per square inch, *c*.	Compression piece cut from beam. Modu-lus of elastici-ty, *E*.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18	
	Grams.	*Grams.*	*Grams*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Inches.*	*Inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 pounds.*		*Pounds.*	*1,000 lbs.*	
A 1......	1,240	1,260	12	29.0	30.1	27.4	30.3	1.97	1.97	815	5,750	3,530	1,019	....	2,880	604	Soaked. Soaked in water for 50 days from April 15. Stood in air 2 days to dry off surface, then thoroughly wet and put in damp box 2 days. The water had penetrated only skin deep, the interior being uniformly damp.
B 1......	1,307	1,368	17	31.5	33.2	30.2	32.7	1.99	1.99	755	5,180	2,750	1,181	....	2,580	625	
C 1......	1,165	1,235	14	31.0	31.4	29.7	32.6	1.97	2.00	720	5,010	2,780	1,292	....	2,550	652	
D 1......	1,210	1,230	20	30.7	30.9	29.3	31.6	2.00	1.99	750	5,080	2,820	1,230	....			
G 1......	1,227	1,260	13	31.2	32.1	29.4	33.2	1.98	1.99	765	5,290	4,160	1,260	....	....	....	
H 1......	1,445	1,510	14	32.5	32.1	......	......	2.01	2.00	720	4,800	3,340	1,158	....	....	....	
I 1......	1,207	1,332	13	32.3	32.0	30.3	34.7	2.00	1.99	775	5,260	4,030	1,464	....	....	....	
J 1......	1,252	1,262	20	29.7	30.1	28.6	30.3	1.98	2.00	780	5,370	3,240	1,350	....	....	....	
K 1......	1,200	1,267	25	29.6	30.5	28.5	30.7	2.00	1.98	765	5,210	2,700	1,473	....	....	....	
L 1......	1,175	1,185	20	30.4	31.3	29.2	31.8	2.02	2.00	645	4,260	2,640	1,179	....	....	....	
M 1......	1,210	1,295	29	29.6	30.2	28.2	30.7	2.00	1.99	745	5,050	2,350	1,212	....	2,550	525	
O 1......	1,310	1,312	14	29.3	30.7	28.3	30.6	1.96	1.95	795	5,730	3,600	1,323	....	2,840	637	
Average.	1,246	1,293	18	30.6	31.3	29.0	31.7	1.99	1.99	753	5,166	3,162	1,262	....	2,680	608.6	
A 2......	1,224	1,224	15	26.1	26.6	23.2	28.6	1.945	1.97	750	5,400	3,640	1,210	0.49	3,050	646	Green. Kept damp 12 to 14 days after being prepared and tested directly.
B 2......	1,340	1,340	28	33.9	32.8	32.5	29.2	1.985	1.99	780	5,350	3,320	1,180	.52	2,850	596	
C 2......	1,200	1,200	14	30.7	30.5	......	......	2.00	1.99	780	5,290	3,060	1,467	.46	....	....	
D 2......	1,164	1,164	13	26.4	24.8	25.0	27.8	1.99	1.97	750	5,200	3,820	....	.45	....	....	
D $2_1{}^a$....	....	....	24	22.6	23.1	20.0	24.1	1.995	1.89	910	6,500	3,320	1,565	....	....	....	
G 2......	1,270	1,270	13	25.7	26.4	23.7	27.6	1.97	1.985	840	5,860	3,230	1,389	.50	....	....	
G $2_1{}^a$....	1,268	1,268	9	35.5	34.4	27.4	48.0	1.985	1.97	840	5,820	4,060	1,272	.49	....	....	
H 2......	1,292	1,292	13	26.9	32.3	25.3	28.5	1.99	2.00	800	5,460	3,420	1,278	.49	....	....	
I 2......	1,212	1,212	13	30.3	28.7	27.9	33.4	1.98	1.97	760	5,320	3,360	1,360	.47	....	....	
J 2......	1,252	1,252	14	28.9	30.6	36.2	30.9	1.975	1.975	900	6,250	3,530	1,379	.49	....	....	
J $2_1{}^a$....	1,226	1,226	16	28.3	31.1	26.2	......	1.985	1.97	850	5,880	3,500	1,511	.48	....	....	
K 2......	1,287	1,287	25	28.4	32.6	31.1	30.7	2.00	2.01	920	6,180	3,620	1,517	.49	....	....	
L 2......	1,197	1,197	18	29.8	28.5	27.6	30.9	1.99	2.02	735	4,970	2,840	1,216	.45	....	....	
M 2......	1,319	1,319	25	26.5	27.6	26.0	30.1	2.00	1.97	910	6,240	3,430	1,134	.51	3,940	678	
O 2......	1,340	1,340	14	33.8	32.6	28.5	42.0	1.95	1.955	835	6,060	3,060	1,600	.54	2,960	630	
Average.	1,257	1,257	17	28.9	29.5	27.2	31.7	1.98	1.98	824	5,719	3,414	1,363	.488	3,025	637.5	

A 4	1,215	1,055	13	9.6	11.2	18.5	12.0	1.945	1.92	1,350	9,980	6,730	1,433		5,650	966	Partly kiln-dried. Dried in kiln for 9 days, 2 days with steam at about 82° F. and 80 per cent humidity, then 4 days with steam at 122° F., then dry air for 3 days at 100° to 122°. Taken out of kiln and kept in desiccator 3 days, then placed in room for 2 to 4 days to equalize moisture distribution.
B 4	1,427	1,211	22	10.6	12.3	10.8	13.7	1.93	1.92	1,680	12,700	7,910	2,170		6,940	1,195	
C 4	1,225	1,017	20	9.0	10.5	9.4	11.7	1.94	1.93	1,420	10,550	5,060	1,655		5,810	934	
D 4	1,235	1,024	18	9.2	10.3			1.91	1.93	1,410	10,800	6,900	1,600				
D 4$_1$[a]	1,240	1,110	21	9.9	10.5			1.97	1.89	1,500	11,030	6,610	1,655				
G 4	1,440	1,092	16	9.7	10.8			1.93	1.91	1,410	10,700	6,540	1,460				
H 4	1,235	1,036	13	9.5	10.6	8.4	10.7	1.94	1.94	1,450	10,730	6,220	1,647				
I 4	1,297	1,057	14	9.9	10.8			1.92	1.93	1,435	10,890	6,840	1,708				
J 4	1,262	1,064	19	10.0	10.0	8.9	11.0	1.95	1.87	1,550	11,770	7,600	1,788				
J 4$_1$[a]	1,235	1,036	19	9.9	10.5	9.1	11.2	1.94	1.92	1,460	10,900	6,730	1,665				
K 4	1,270	1,059	24	9.9	11.0			1.95	1.93	1,580	11,610	6,630	1,765				
L 4	1,190	995	14	9.3	9.5			1.97	1.92	1,350	9,780	5,940	1,500				
M 4	1,192	1,000	24	9.7	10.5			1.95	1.91	1,770	13,160	6,700	1,648		6,160	1,000	
O 4	1,645	1,192	19	11.0	11.8			1.95	1.93	1,510	11,110	5,890	1,648		6,040	994	
Average	1,293	1,076	18	9.8	10.7	10.9	11.7	1.94	1.92	1,491	11,122	6,593	1,667		6,120	1,018	
A 6	1,222	1,040	15	7.6	6.8			1.93	1.92	1,580	11,940	7,560	1,470		7,020	1,000	Nearly kiln-dry. Kiln-dried 12 days as last, except dry air for 6 days at 130°, then placed in desiccator for 4 to 5 days.
B 6	1,435	1,205	21	9.0	8.4			1.93	1.92	1,805	13,620	9,080	2,240		8,310	1,590	
C 6	1,202	993	19	7.5	7.4			1.92	1.92	1,500	11,440	6,490	1,665				
D 6	1,320	1,071	16	7.9	7.3			1.95	1.96	1,545	11,200	6,080	1,575				
D 6$_1$[a]	1,230	1,060	15	8.0	7.7			1.92	1.87	1,510	11,830	8,550	1,745				
G 6	1,454	1,082	17	6.8	7.3			1.91	1.91	1,530	11,840	7,750	1,388				
H 6	1,245	1,030	14	7.9	7.7	6.8	9.4	1.92	1.88	1,550	12,080	7,800	1,701				
I 6	1,395	1,000	13	7.6	7.1	7.0	9.0	1.90	1.90	1,540	12,110	7,090	1,791				
J 6	1,227	1,008	18	8.0	7.7			1.90	1.90	1,630	12,820	7,090	1,756				
K 6	1,217	1,005	16	7.6	7.1			1.98	1.88	1,720	12,600	7,030	1,730				
L 6	1,159	950	12	6.6	6.8			1.93	1.92	1,500	11,320	7,180	1,565				
M 6	1,245	993	25	7.8	7.3			1.91	1.87	1,720	13,610	8,560	1,790		7,500	1,200	
O 6	1,747	1,120	18	8.4	7.4			1.95	1.90	1,810	13,510	6,730	1,655				
Average	1,315	1,042	16	7.7	7.4	6.9	9.2	1.93	1.90	1,611	12,302	7,507	1,699		7,610	1,263	
A 7	1,202	977	11	3.1		2.9	3.3	1.91	1.94	1,250	9,530			.40			Kiln-dry. Kiln-dried for 20 days as No. 4, except dry air at about 130° F. for 14 days. Taken out of kiln and placed in desiccator for 3 days, then returned to kiln for 3 or 4 days more. Cooled in desiccator before testing.
B 7	1,309	1,067	25	3.4	4.5	7.3	10.4	1.89	1.88	1,890	15,200	9,650	1,839	.46			
C 7	1,144	953	17	4.4	3.4	2.9	4.3	1.91	1.90	1,720	13,400	8,560	1,632	.40			
D 7	1,197	992	14	4.5	3.9	3.6	5.6	1.92	1.92	1,720	13,120	8,380	1,788	.41			
D 7$_1$[a]	1,220	1,047	20	4.5				1.95	1.87	1,700	13,310	8,360	1,718	.44			
G 7	1,205	950	13	3.7	3.4			1.92	1.87	1,740	13,640	8,620	1,764	.40			
H 7	1,285	1,005	12	3.4	2.9			1.93	1.88	1,480	11,410	8,480	1,462	.42			
I 7	1,310	1,038	12	3.8	3.6			1.89	1.88	1,870	15,030	8,850	1,839	.44	9,240	1,250	
J 7	1,203	988	20	4.1	3.1			1.89	1.89	1,660	13,300	8,250	1,828	.42			
K 7	1,310	1,025	20	4.0	3.1			1.89	1.88	1,880	15,120	11,800	1,839	.42	9,110	1,300	
L 7	1,262	988	13	4.1	3.6			1.95	1.97	1,680	12,100		1,597	.39			
M 7	1,415	962	22	3.3	3.1			1.91	1.87	1,780	14,100	8,700	1,701	.41	8,920	1,270	
O 7	1,540	1,062	18	4.4	3.9			1.91	1.89	2,075	16,250	11,330	2,000	.45	10,070	1,415	
Average	1,277	1,004	17	3.9	3.5	4.2	5.9	1.91	1.89	1,726	13,502	9,180	1,751	.420	9,335	1,309	

[a] Placed in machine with rings horizontal.

TABLE 6.—*Spruce, bending tests. Size, 2 by 2 by 40 inches. Span, 36 inches*—Continued.

REABSORPTION.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. At ½ span, disk *c*.	Moisture. Disk *x*. Outside.	Moisture. Disk *x*. Inside.	Dimensions at center. Height.	Dimensions at center. Width.	Maximum center load.	Modulus of rupture, *R*.	Stress at elastic limit, *f*.	Modulus of elasticity, E.	Specific gravity.	Compression piece cut from beam. Crushing strength per square inch, *c*.	Compression piece cut from beam. Modulus of elasticity, *E*.	Weight when kiln-dry.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18		
	Grams.	*Grams.*	*Grams*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Inches.*	*Inches.*	*Lbs.*	*Lbs.*	*Lbs.*	*1,000 pounds.*		*Pounds.*	*1,000 lbs.*	*Grams.*	
A 3......	1,267	1,765	15	66.8	....	......	......	1.98	2.02	695	4,740	2,940	1,240	....	....	....	1,014	
B 3......	1,330	1,810	28	60.5	....	86.6	33.0	2.00	2.03	730	4,850	3,880	958	....	2,520	508	1,060	Resoaked. Kiln-dried for 28 days as No. 4, except dry air for 22 days at 124° to 138° F., averaging 130°, then soaked for 84 days. (Interior was not water soaked.)
C 3......	1,180	1,603	18	56.3	....	......	......	2.01	2.03	655	4,310	2,700	1,240	....	....	....	937	
D 3......	1,162	1,640	22	56.5	....	......	......	2.01	2.01	630	4,180	2,660	1,123	....	....	....	955	
G 3......	1,270	1,770	12	64.5	....	......	......	2.02	2.00	690	4,560	2,710	1,350	....	....	....	970	
I 3......	1,240	1,740	14	60.4	....	90.6	34.0	2.01	2.00	690	4,600	2,740	1,052	....	....	....	975	
J 3......	1,272	1,620	12	52.8	....	......	......	2.00	2.00	640	4,320	2,730	1,215	....	....	....	945	
K 3......	1,212	1,740	26	50.4	....	......	......	2.03	2.03	700	4,520	2,710	1,127	....	....	....	1,007	
L 3......	1,170	1,715	17	67.2	....	......	......	2.03	2.03	645	4,160	2,710	996	....	....	....	935	
M 3......	1,285	1,680	33	60.0	....	87.0	36.0	2.02	2.00	660	4,350	2,770	1,080	....	....	....	945	
Average.	1,239	1,709	19	59.5	....	88.1	34.5	2.01	2.02	674	4,459	2,855	1,148.1	....	....	....	974	

TABLE 7.—*Chestnut, bending tests. Size 2 by 2 by 40 inches, span, 36 inches.*

Regarding lumber from which specimens were cut see Table 3.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture. At break, disk *a*	Moisture. ¼ span disk *c*.	Moisture. Disk *x*. Outside.	Moisture. Disk *x*. Inside.	Dimensions at center. Height.	Dimensions at center. Width.	Maximum load.	Modulus of rupture, *R*.	Stress at elastic limit, *f*.	Modulus of elasticity, *E*.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Grams.	*Grams.*		*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Inches.*	*Inches.*	*Pounds*	*Pounds.*	*Pounds.*	*1,000 pounds.*		
1	2,540	2,670	9	166	168	170	162	2.04	2.03	975	6,240	3,890	984	....	Soaked. Soaked in water for 25 days from May 21. (9 out of the 10 specimens sank in water.)
11	2,260	2,380	9	125	126	123	126	2.02	2.02	1,080	7,060	3,990	1,290	....	
21	2,520	2,680	6	149	160	159	140	2.02	2.02	950	6,210	2,940	1,148	....	
31	2,770	2,860	8	125	130	130	125	2.00	2.00	960	6,490	4,180	1,257	....	
41	2,440	2,640	8	113	115	124	104	1.98	2.01	830	5,690	3,290	1,131	....	
51	2,440	2,640	7	129	131	......	......	2.00	1.99	780	5,300	2,710	968	....	
61	2,630	2,770	5	......	......	......	......	2.00	1.99	N. G.	......	......	......	....	
71	2,660	2,800	7	130	129	......	......	2.01	2.01	985	6,560	4,050	848	....	
81	2,570	2,730	5	......	......	......	......	2.00	2.00	N. G.	......	......	......	....	
91	2,650	2,770	7	122	125	......	......	2.01	2.01	1,085	7,210	4,050	946	....	
Average	2,548	2,694	7	132	135	141	131	2.01	2.01	959	6,345	3,638	1,072	....	
2	2,450	2,450	6	133	139	......	......	2.00	2.00	1,025	6,920	3,640	1,213	0.93	Green. Tested directly, kept damp 2 days.
2_1	2,450	2,450	10	134	131	......	......	2.00	2.00	1,035	7,000	4,730	1,213	.93	
12	2,170	2,170	11	110	113	......	......	2.02	2.00	915	6,040	3,170	1,430	.82	
22	2,460	2,460	6	134	136	......	......	2.01	2.02	900	5,950	3,310	1,164	.93	
32	2,750	2,710	5	126	116	......	......	2.00	2.00	1,125	7,600	4,730	1,041	1.03	
42	2,430	2,430	7	109	105	......	......	2.00	1.97	785	5,380	2,990	962	.94	
52	....	....	12	123	122	115	132	2.01	2.00	675	4,500	2,740	718	....	
62	2,520	2,520	6	121	120	......	......	1.99	1.99	775	5,310	2,740	744	.97	
72	2,480	2,480	6	113	111	112	110	2.00	2.00	885	5,970	3,370	935	.95	
82	2,580	2,580	4	100	101	89	107	1.98	1.99	885	6,130	2,830	1,207	1.00	
92	2,580	2,550	6	101	104	......	......	2.01	2.01	1,100	7,310	4,250	1,071	.98	
Average	2,481	2,481	6	119	118	100	116	2.00	2.00	919	6,192	3,500	1,064	.95	

TABLE 7.—*Chestnut, bending tests. Size 2 by 2 by 40 inches, span, 36 inches*—Continued.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. ½ span disk *c*.	Moisture. Disk *x*. Outside.	Moisture. Disk *x*. Inside.	Dimensions at center. Height.	Dimensions at center. Width.	Maximum load.	Modulus of rupture, *R*.	Stress at elastic limit, *f*.	Modulus of elasticity, *E*.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Grams.	*Grams.*		*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Inches.*	*Inches.*	*Pounds.*	*Pounds.*	*Pounds.*	*1,000 pounds.*		
6	2,390	1,295	6	25.0	....	23.9	26.3	1.96	1.97	945	6,750	4,280	1,248	....	Damp. Kiln-dried with steam at 130° to 140° F. and 75 to 80 per cent humidity for 26 days (drier at night), then soaked for one night and placed in damp box for 45 days. See No. 3 below, also No. 4.
16	2,210	1,330	9	23.7	....	....	....	1.99	1.98	975	6,730	4,140	1,246	....	
46	2,280	1,500	9	23.3	25.6	....	....	2.00	1.99	725	4,920	2,710	832	....	
53	2,390	1,410	9	24.0	24.1	25.4	23.3	1.98	2.00	775	5,340	2,960	723	....	
63	2,570	1,580	7	32.7	....	30.0	36.9	1.98	1.97	875	6,120	3,470	767	....	
73	2,590	1,525	8	38.0	....	24.2	67.1	1.96	1.98	775	5,500	3,550	782	....	
83	2,610	1,550	4	26.2	....	....	....	1.98	1.97	885	6,190	4,540	780	....	
93	2,550	1,585	6	37.9	....	....	....	1.99	2.00	750	4,780	3,070	700	....	
Average	2,498	1,472	7	28.9	24.8	25.9	38.4	1.98	1.98	832	5,791	3,590	885	....	
4	2,420	1,175	8	19.3	13.8	11.3	97.	1.94	1.92	1,275	9,540	6,740	1,451	....	Partly kiln-dry. Kiln-dried as last for 26 days. (The free water in the interior had disappeared except a small spot in one specimen.)
14	2,310	1,187	9	15.2	16.8	10.8	22.0	1.91	1.95	1,125	8,550	5,320	1,438	....	
24	2,540	1,205	5	17.0	14.9	11.0	25.0	1.95	1.94	1,190	8,720	5,860	1,272	....	
34	2,760	1,407	6	....	....	....	....	1.95	1.91	N. G.	....	....	....	....	
44	3,200	1,250	6	10.1	11.8	9.5	10.9	1.96	1.86	1,375	10,380	5,290	1,261	....	
54	2,220	1,177	13	10.9	9.7	9.8	11.5	1.94	1.93	1,340	9,960	5,210	1,053	....	
64	2,550	1,330	6	17.2	13.4	11.5	24.4	1.96	1.92	1,075	7,870	4,760	832	....	
74	2,560	1,460	5	20.8	14.4	11.9	38.3	1.96	1.95	1,075	7,750	5,050	1,133	....	
84	2,490	1,410	5	13.3	10.8	10.6	16.1	1.94	1.95	1,415	10,410	5,900	1,295	....	
94	2,680	1,500	7	18.9	17.9	11.8	30.4	1.98	1.98	1,285	8,950	5,900	1,179	....	
Average	2,582	1,310	7	15.9	13.7	10.9	30.6	1.95	1.93	1,239	9,126	5,560	1,214	....	

5	2,270	1,040	6	4.8	4.4	3.4	6.0	1.92	1.91	1,585	12,200	8,450	1,597	.43	Kiln-dry. Kiln-dried 39 days, with steam as No. 6 for 26 days, then dry heat at 140° F. for 13 days. (Cooled in desiccator before testing.)
5 [b]	2,430	1,080	7	5.1	4.8	......	......	1.95	1.85	1,550	11,900	8,070	1,687	.46	
15	2,120	1,070	8	4.7	4.7	2.8	5.8	1.92	1.92	1,780	13,570	10,300	1,665	.44	
25	2,380	1,130	5	5.1	4.7	3.5	6.3	1.92	1.91	1,355	10,390	9,840	1,665	(.47)	
35	2,660	1,270	7	5.1	4.7	3.1	5.8	1.93	1.88	1,685	13,000	9,660	1,289	.53	
45	2,280	1,110	11	4.3	4.3	......	......	1.91	1.89	1,495	11,700	7,210	1,258	.47	
55	2,210	1,100	12	3.4	3.5	......	......	1.91	1.89	1,570	12,300	6,270	1,222	.47	
65 [a]	2,570	1,210	7	5.3	5.6	4.0	6.6	1.91	1.90	1,035	8,080	......	......	.51	
75	2,600	1,280	9	6.6	5.7	......	......	1.95	1.89	1,100	8,270	6,010	1,250	.53	
85	2,450	1,290	6	4.8	4.3	......	......	1.91	1.88	1,690	13,300	7,870	1,437	.55	
95	2,580	1,250	6	5.7	5.4	......	......	1.90	1.90	1,275	10,030	7,870	1,318	.53	
Average	2,418	1,166	8	5.0	4.6	3.4	6.1	1.92	1.89	1,466	11,340	8,155	1,439	.49	
3	2,300	1,450	8	54	45	19.2	104	1.97	1.97	1,010	7,140	4,900	1,260	......	Casehardened. Kiln-dried with steam as No. 6 for 7 days, then left in room 3 days. (It was found that the center was still wet with free-water while surface was quite dry.) These tests were discarded in the general average.
13	2,220	1,430	8	41	37.9	17.3	76.2	1.98	1.98	995	6,930	4,180	1,320	......	
23	2,580	1,630	6	64	74	19.2	118	1.99	1.99	1,020	7,000	4,790	1,119	......	
33	2,680	1,780	4	52	43	19.7	95	1.98	1.98	1,170	8,140	4,870	1,223	......	
43	2,340	1,440	7	34.5	32.2	16.8	70	1.95	1.93	880	6,470	4,190	958	......	
Average	2,430	1,546	7	49.0	46.7	18.4	93	1.97	1.97	1,015	7,134	4,586	1,176	......	

[a] Irregular stress diagram.

[b] Placed in machine with rings horizontal.

REABSORPTION.

No. of test piece.	Weight when cut.	Weight at test.	Rings per inch.	Moisture. At break, disk *a*.	Moisture. ½ span disk *c*.	Moisture. Disk *x*. Out-side.	Moisture. Disk *x*. In-side.	Dimensions at center. Height.	Dimensions at center. Width.	Maxi-mum load.	Modulus of rup-ture, *R*.	Stress at elastic limit. *f*	Modulus of elas-ticity, *E*.	Weight when kiln dry.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Grams.	*Grams.*		*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Pr. ct.*	*Inches.*	*Inches.*	*Pounds*	*Pounds.*	*Pounds.*	*1,000 pounds.*		
17	2,310	1,670	5	51.1	......	90.2	20.0	1.98	1.97	850	5,940	3,500	1,523	1,100	Resoaked. Kiln-dried as No. 5 for 40 days, then soaked in water for 35 days from July 1.
47	2,310	1,970	7	62.8	......	......	......	1.97	1.98	650	4,570	2,460	976	1,215	
57	2,210	1,930	3	60.0	42.1	96.0	26.9	1.98	1.99	675	4,670	3,320	945	1,180	
67	2,730	1,850	5	47.8	......	......	......	1.96	1.95	720	5,190	2,880	616	1,770	
Average	2,390	1,855	5	55.3	42.1	93.1	23.4	1.97	1.97	724	5,092	3,040	1,015	1,318	

SHEARING.

(Tables 8, 9, 10, and 11.)

The shearing tests were made upon the Olsen machine by means of an apparatus designed for this purpose by Dr. W. K. Hatt. An explanation first of the preparation of the specimen will be necessary in order to give a clear understanding of the way in which these tests were made. The piece had been brought to the desired moisture condition, as already explained, as a 2" by 2 by 6 inch block. The two ends were now cut off on the smooth-cutting circular saw, making the piece exactly 3 inches long, and thus eliminating end checks. Next a transverse strip one-half inch square was cut from either end on the same side, thus leaving a tenon projecting one-half inch on this side and 2 by 2 inches square. This tenon was to be sheared off vertically (i. e. in the direction of the grain), thus giving a single shearing surface of 4 square inches. In order to secure a clear, free shear without any compression from below, the cut under the tenon was extended a short distance horizontally into the block.

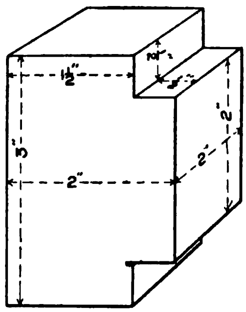

FIG. 3.—Block prepared for shearing test.

It should be noted that the proportions of the area of shear form an important consideration, since, if the length of the tenon to be sheared off were too great in the direction of the shearing force, failure would occur by compression before the piece would shear. Now, since the compression strength along the grain is sometimes not more than five times the shearing strength, it follows that the shearing surface should be less than five times the surface to which the pressure is applied. The pressure surface of the tenon is one-half a square inch for every inch of its width; therefore the shearing surface should be less than five times this, or less than 2½ inches in length vertically. Since the vertical length in the test specimens is 2 inches the condition is fulfilled.

The shearing apparatus referred to consists of a solid steel frame of convenient shape and size for clamping the block within it firmly in a vertical position by means of set screws. The tenon of the specimen projects over a vertical slot in the center of the frame, in which slot slides freely a plate one-half inch thick, with rectangular edges. This plate impinges squarely along the upper surface of the tenon, and as vertical pressure is applied to the plate the tenon is sheared off. This apparatus, with the test specimen properly adjusted within it, is placed upon the platform of the machine and pressure applied steadily until failure occurs.

In order to avoid, as far as possible, all friction due to lateral pressure of the plate against the bearings of the groove, the mechan-

FIG. 1.—KILN-DRY SPRUCE.

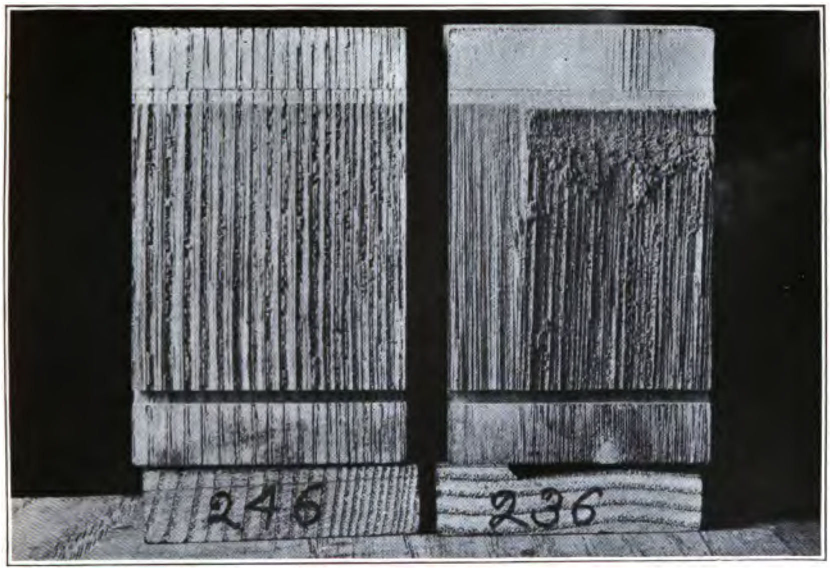

FIG. 2.—KILN-DRY CHESTNUT.

FIG. 3.—GREEN LONGLEAF PINE.

MANNER OF FAILURE IN SHEARING TESTS PARALLEL TO GRAIN, TANGENTIAL AND RADIAL TO ANNUAL RINGS.

ism was placed upon a roller base, consisting of five $\frac{3}{4}$-inch parallel steel rods. Thus it was assured that the pressure was perpendicular to the platform. The same speed of the machine was used as for the endwise compression tests, namely, about 0.01 inch per minute. Deflections were not recorded, since they would have no significance, and the only readings taken were the time of starting and ending the test and the maximum shearing load attained. There is no true elastic limit. The various weights, dimensions, etc., were recorded as in all the tests.

In these tests the grain is always vertical and the shearing surface either radial or tangential to the annual rings. In the longleaf pine three series were made with the shearing plane radial and five series tangential. In the spruce there were five series radial and eleven series tangential, and in the chestnut five series of each.

In each series, however, one green piece was tested with the opposite kind of shear, in order to get a direct comparison of the radial and tangential kinds. The difference, although showing a slightly increased strength in the case of the radial shear in some instances, does not appear to be decided enough to draw a distinction between the two kinds. In the case of wood with strong medullary rays, such as oak, the shearing strength is stronger in the tangential plane. In the longleaf pine the radial shear, crossing the rings at right angles, is sometimes in excess of the tangential, but it is as apt to be the other way, since the wood is more susceptible to small checks occurring in the radial direction than in any other.

The results show that although the shearing strength normally increases rapidly with dryness, it can not be depended upon to do so. Even when no checks whatever are visible the piece is sometimes unduly weak in shear. This irregularity in the shearing strength is probably accounted for by the internal stresses during drying, which may be sufficient to produce partial splitting of the walls of the fibers lengthwise without causing any visible checks. This would be especially the case with large timbers, and while the average results, as given in Table 20 and Plate III, show an increase in strength with dryness this must not be considered as generally applicable to single specimens. The longleaf pine is the most irregular of the three species.

TABLE 8.—*Spruce, shearing. Lot of 1903.*

For lumber see note for spruce compression tests, Table 3. Treated in 6-inch lengths.

No. of test piece.	Kind of shear.[a]	Weight when out (6 inches long).	Weight at test (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq. in.*	*Lbs.*	*Lbs. per sq. in.*		
201	T.	172	228	10	3	38.6	3.98	2,300	704	.....	Soaked. Soaked in water 22 days, from Feb. 16, 1904, after remaining in damp box outdoors all winter.
211	T.	192	253	16	4	79.0	4.00	3,000	750	.....	
221	T.	200	251	25	7	34.9	4.06	2,865	706	.....	
231	T.	.....	.....	.....	.....	.....	.....	.....	.....	.....	
241	T.	177	230	19	4	39.7	4.10	2,750	671	.....	
251	R.	189	222	23	42	35.2	3.96	1,900	480	.....	
261	R.	196	259	12	22	47.3	......	2,900	[b](725)	.....	
271	R.	175	229	14	27	36.9	......	2,810	[b](705)	.....	
Average	....	186	239	17	......	44.5	4.02	2,717	677	.....	
202	T.	180	180	11	1	22.6	3.94	3,240	823	.....	Green. Kept in damp box all winter outdoors, from October, 1903, until tested Feb. 29, 1904.
212	T.	192	192	16	7	24.7	4.06	3,640	896	.....	
222	T.	200	200	25	10	22.7	4.07	4,100	1,005	.....	
232	T.	190	190	17	6	22.8	4.04	3,810	944	.....	
242	T.	180	180	19	2	22.6	4.13	3,430	832	.....	
252	R.	187	187	18	34	21.9	3.96	3,550	897	.....	
262	R.	194	194	13	25	22.9	3.96	3,240	819	.....	
272	R.	178	198	16	32	21.7	4.02	3,150	784	.....	
Average	....	188	188	17	......	22.7	4.02	3,520	875	.....	
202[1]	R.	174	174	9	21	14.7	3.90	3,375	865	.....	Green. Same treatment as last. Opposite kinds of shear.
212[1]	R.	196	196	16	30	N.G.	4.00	......	......	.....	
222[1]	R.	200	200	27	44	21.3	4.04	4,080	1,010	.....	
232[1]	R.	195	195	20	40	23.7	4.09	3,060	748	.....	
242[1]	R.	184	184	19	42	23.0	4.12	3,750	910	.....	
252[1]	T.	184	184	14	5	22.8	4.02	3,750	932	.....	
262[1]	T.	192	192	13	8	23.9	3.98	3,335	838	.....	
272[1]	T.	165	165	9	4	20.9	4.03	3,430	852	.....	
Average	....	186	186	16	......	21.4	4.02	3,540	879	.....	
204	T.	172	159	10	3	9.2	3.86	4,130	1,070	.....	Partly kiln-dried. Dried in kiln with steam for 15 days, cool at first and then raised to 100° to 120° F., followed by dry heat for 3 days.
214	T.	195	169	14	3	9.9	3.84	4,775	1,240	.....	
224	T.	188	168	14	3	10.2	3.88	3,930	1,010	.....	
234	T.	186	170	19	5	9.6	3.84	3,700	964	.....	
244	T	177	162	18	5	10.0	3.80	4,940	1,300	.....	
254	R.	200	177	21	40	10.1	3.97	5,160	1,300	.....	
264	R.	195	176	11	22	9.9	3.90	5,230	1,340	.....	
274	R.	167	152	8	15	9.7	3.86	4,100	1,060	.....	
Average	....	185	167	14	......	9.8	3.87	4,496	1,161	.....	
206	T.	170	151	11	2	5.1	3.86	4,790	1,240	.....	Partly kiln-dried. Dried as last, except dry heat for 12 days.
216	T.	198	161	13	2	4.7	3.73	4,860	1,300	.....	
226	T.	189	159	19	3	4.9	3.81	5,080	1,330	.....	
236	T.	180	157	18	2	5.2	4.02	5,370	1,340	.....	
246	T.	192	160	20	1	5.3	3.75	4,420	1,180	.....	
256	R.	221	153	18	36	4.9	3.88	4,900	1,260	.....	
266	R.	195	167	12	23	5.0	3.88	4,400	1,130	.....	
276	R.	176	153	7	14	5.2	3.90	4,515	1,160	.....	
Average	....	190	158	15	......	5.0	3.85	4,792	1,243	.....	
207	T.	181	157	11	2	4.2	3.75	3,730	995	.....	Kiln-dry. Dried as No. 204, except dry heat for 22 days, 37 days in all.
217	T.	203	164	16	1	4.3	3.73	5,450	1,460	.....	
227	T.	189	158	16	3	4.3	3.84	4,140	1,080	.....	
237	T.	180	155	20	1	4.4	3.81	3,830	1,005	.....	
247	T.	177	......	22	1	4.0	3.69	4,870	1,320	.....	
257	R.	244	150	20	39	4.0	3.73	4,680	1,255	.....	
267	R.	197	167	14	27	4.1	3.79	3,760	992	.....	
277	R.	170	148	15	30	4.1	3.84	3,320	865	.....	
Average	....	193	157	17	......	4.2	3.77	4,223	1,122	.....	

[a] T=tangential; R=radial.

[b] Area estimated.

TABLE 8.—*Spruce, shearing. Lot of 1903*—Continued.

No. of test piece.	Kind of shear.[a]	Weight when cut (6 inches long).	Weight at test (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr.ct.*	*Sq.in.*	*Lbs.*	*Lbs. per sq. in.*		
207[1]........	T.	178	150	10	2	0.7	3.67	5.310	1,450	0.42	Oven dry. Kiln-dried as No. 204 for 33 days, then kept in oven at 208° F. 8 hours a day for 6 days cooling off at nights.
217[1]........	T.	190	152	16	3	.6	3.69	4,200	1,140	.43	
227[1]........	T.	186	151	31	3	.7	3.71	2,920	788	.43	
237[1]........	T.	179	147	20	2	.6	3.67	4,080	1,110	.42	
247[1]........	T.	180	150	21	3	.7	3.63	4,820	1,330	.43	
257[1]........	R.	225	148	18	35	.7	3.81	3,640	956	.42	
267[1]........	R.	195	160	12	24	.7	3.82	6,810	1,780	.45	
277[1]........	R.	169	140	15	29	.5	3.83	3,270	855	.38	
Average.	....	188	150	18	......	.7	3.73	4,381	1,176	.42	

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No. of test piece.	Kind of shear.[a]	Weight when cut (6 inches long).	Weight at test (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Weight when kiln-dry (6 inches long).	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	12	
		Grms	*Grms*				*Sq. in.*	*Pounds.*	*Lbs. per sq. in.*		
208.........	T.	185	164	13	1	8.6	4.02	4,350	1,080	157	Reabsorbed. Kiln-dried as No. 204 but for 2 months, then placed in room 43 days until tested.
218.........	T.	196	164	17	3	8.7	3.81	3,500	919	157	
228.........	T.	187	167	13	1	8.6	3.90	4,750	1,220	161	
238.........	T.	180	164	19	4	8.5	3.86	4,825	1,250	158	
248.........	T.	179	160	18	4	8.7	[a](3.79)	[a](2,615)	[a](690)	154	
258.........	R.	190	166	22	44	9.0	3.94	4,015	1,020	159	
268.........	R.	192	172	13	26	8.2	3.94	4,960	1,260	165	
278.........	R.	163	149	8	16	9.1	3.96	4,050	1,020	142	
Average.	....	184	163	15	....	8.7	3.92	4,350	1,110	157	
205.........	T.	170	245	14	2	33.1	4.08	2,510	615	150	Resoaked. Kiln-dried as No. 208 for 2 months, then soaked for 30 days. (Only the ends and a thin skin were water soaked, the former being trimmed off before testing and the latter before weighing the disks.)
215.........	T.	199	293	13	1	26.6	4.04	2,625	650	164	
225.........	T.	190	246	17	2	33.3	4.06	2,380	587	158	
235.........	T.	180	250	20	3	32.5	4.14	2,430	588	155	
245.........	T.	185	253	18	4	32.5	4.06	2,150	530	156	
255.........	R.	192	249	16	32	30.2	4.06	2,400	591	161	
265.........	R.	192	273	11	22	35.1	4.04	2,000	495	164	
275.........	R.	169	232	7	13	32.5	4.02	2,250	560	145	
Average.	....	185	255	15	....	32.0	4.06	2,343	577	157	

[a] Weak; not included in average.

TABLE 9.—*Spruce, shearing. Lot of 1904.*

For lumber see note for Spruce Compression Tests, Table 2. Treated in 6-inch lengths. Cut to 6-inch lengths April 21, 1904.

No. of test piece.	Kind of shear.	Weight when cut (6 inches long).	Weight at test, (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq. in.*	*Lbs.*	*Lbs. per sq. in.*		
A 201	Tangential.	170	235	10	2	47.8	4.02	1,925	478	......	Soaked. Soaked in water for 35 days from April 22.
B 201		198	262	32	5	46.8	4.06	2,540	626	......	
B 221		168	227	28	7	50.6	4.02	2,725	678	......	
B 241		189	253	23	5	48.4	4.06	2,570	633	......	
C 201		170	227	15	2	52.7	4.00	2,075	519	......	
L 201		165	225	17	2	54.3	3.98	2,175	547	......	
M 201		187	243	26	3	43.5	4.00	2,765	691	......	
O 201		200	255	21	2	51.7	4.09	2,835	694	......	
Average	....	187	241	22	4	49.5	4.03	2,450	608	......	
A 202	Tangential.	173	173	11	3	22.9	4.00	3,500	875	0.45	Green. Kept damp 2 to 4 days until tested.
B 202		201	201	22	5	22.4	3.97	3,030	764	.52	
B 222		202	202	29	3	23.1	4.02	3,550	882	.52	
B 242		204	204	21	3	23.0	4.04	3,175	785	.53	
C 202		174	174	15	1	25.4	3.98	2,730	686	.45	
L 202		166	166	14	2	21.4	3.94	2,810	714	.43	
M 202		193	193	23	3	22.7	4.00	3,475	869	.50	
O 202		203	203	15	4	25.1	4.10	3,580	875	.52	
Average	....	190	190	19	3	23.2	4.00	3,231	806	.490	
$A\ 202_1$	Radial.	173	173	11	23	19.9	3.97	3,030	764	.45	Green. Same as last.
$B\ 202_1$		200	200	29	30	24.8	3.98	3,230	812	.52	
$B\ 222_1$		208	208	26	51	26.8	4.08	3,660	898	.54	
$B\ 242_1$		204	204	23	44	22.3	3.95	3,360	850	.53	
$C\ 202_1$		172	172	14	27	22.9	4.02	2,730	678	.44	
$L\ 202_1$		167	167	17	32	20.6	4.00	3,120	780	.43	
$M\ 202_1$		193	193	23	46	22.6	4.12	3,585	870	.50	
$O\ 202_1$		210	210	23	37	25.5	4.11	3,000	731	.53	
Average	....	191	191	21	36	23.2	4.03	3,214	798	.490	
A 204	Tangential.	170	159	12	6	11.7	3.82	4,200	1,100	......	Air-dried. Stood in room, with ends covered, 7 days.
B 214		195	178	26	6	13.1	3.58	4,270	1,190	......	
B 224		200	184	27	3	13.1	3.67	3,550	968	......	
B 244		192	176	21	4	12.6	3.75	3,560	950	......	
C 204		177	157	16	2	12.4	3.79	3,350	885	......	
L 204		165	151	21	3	12.2	3.69	3,960	1,070	......	
M 204		195	181	22	3	12.9	3.79	3,760	992	......	
O 204		212	186	20	11	14.4	3.84	4,240	1,100	......	
Average	....	187	172	21	5	12.8	3.74	3,862	1,032	......	
A 206	Tangential.	176	157	10	6	12.7	3.79	3,480	918	......	Partly kiln-dried. Dried in kiln with steam at 120° to 130° F. and 80 per cent humidity for 4 days; then dry heat at same temperature for 2 days.
B 206		195	174	21	5	12.1	3.75	3,090	825	......	
B 226		202	185	25	2	11.7	3.69	3,050	827	......	
B 246		189	170	29	11	11.6	3.67	3,340	910	......	
C 206		170	152	14	2	10.5	3.75	3,540	945	......	
L 206		167	150	15	3	10.2	3.73	3,640	976	......	
M 206		178	159	25	11	10.2	3.79	3,200	845	......	
O 206		184	166	21	5	11.0	3.77	4,000	1,060	......	
Average	....	183	164	20	6	11.3	3.73	3,417	913	......	
A 207	Tangential.	167	145	7	4	4.4	3.85	6,260	1,630	.41	Kiln-dry. Dried as above, except dry heat for 13 days.
B 207		195	161	28	7	3.8	3.71	5,780	1,560	.45	
B 227		205	168	26	2	3.7	3.69	6,135	1,660	.47	
B 247		189	154	20	4	3.9	3.75	6,975	1,860	.42	
C 207		174	143	16	2	3.7	3.75	5,415	1,440	.39	
L 207		170	139	21	1	3.9	3.81	5,715	1,500	.39	
M 207		187	156	25	1	3.9	3.81	4,850	1,270	.43	
O 207		183	151	19	3	3.6	3.75	5,380	1,430	.43	
Average	....	184	152	20	3	3.9	3.76	5,813	1,544	.424	

TABLE 9.—*Spruce, shearing. Lot of 1904*—Continued.

No. of test piece.	Kind of shear.	Weight when cut (6 inches long).	Weight at test, (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr.ct.*	*Sq.in.*	*Lbs.*	*Lbs. per sq. in.*		
A 207_1......	Tangential.	177	142	10	2	1.1	3.73	6,470	1,730	0.41	Oven dry. Kiln-dried as No. 6, except dry heat for 9 days; then placed in oven at 208° F. for 8 hours a day for 6 days.
B 207_1......		203	165	28	6	1.0	3.65	4,380	1,200	.48	
B 227_1......		201	164	27	2	1.1	3.65	5,850	1,600	.48	
B 247_1......		187	148	18	3	1.2	3.69	6,100	1,650	.44	
C 207_1......		172	138	16	2	1.0	3.65	4,500	1,230	.40	
L 207_1......		174	137	20	5	1.1	3.75	5,090	1,360	.38	
M 207_1......		191	155	16	5	1.1	3.73	4,600	1,230	.44	
O 207_1......		185	148	18	5	0.9	3.77	5,160	1,370	.43	
Average.	....	186	150	19	4	1.1	3.70	5,268	1,421	.432	

REABSORPTION.

No. of test piece.	Kind of shear.	Weight when cut (6 inches long).	Weight at test, (6 inches long).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Weight when kiln-dry (6 inches long).	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq.in.*	*Lbs.*	*Lbs. per sq. in.*	*Lbs.*	
A 208......	Tangential.	175	158	10	2	10.5	3.86	4,800	1,240	140	Reabsorbed. Kiln-dried as No. 6 for 26 days; then stood in room for 23 days.
B 208......		205	182	30	12	9.8	3.78	4,550	1,200	162	
B 228......		198	177	21	3	10.2	3.88	4,025	1,040	157	
B 248......		189	155	22	5	10.2	3.78	4,900	1,300	147	
C 208......		169	151	14	4	10.2	3.74	3,975	1,060	134	
L 208......		172	152	24	3	10.1	3.82	3,750	982	134	
M 208......		192	173	27	2	10.5	3.78	4,675	1,240	153	
O 208......		185	163	16	3	10.3	3.84	4,125	1,070	144	
Average.	....	186	165	21	4	10.2	3.80	4,350	1,141	146	
A 205......	Tangential.	169	......	11	5	22.9	4.00	2,400	500	139	Reabsorbed. Kiln-dried as No. 6 for 26 days; then stood in room 22 days, cut to 3-inch lengths, thoroughly wetted, and placed in damp box for 12 days. (The outer surface was trimmed off of disks before weighing.)
B 205......		192	......	35	8	22.2	3.96	2,810	710	152	
B 225......		162	......	26	2	24.0	3.94	3,120	792	102	
B 245......		190	......	17	34	23.4	4.02	2,390	594	150	
C 205......		174	......	14	4	23.8	4.00	2,530	633	135	
L 205......		162	......	15	2	24.5	3.90	2,610	670	129	
M 205......		181	......	25	5	23.7	4.02	2,940	731	144	
O 205......		215	......	21	10	23.7	4.04	3,185	789	157	
Average.	....	181	......	21	9	23.5	3.98	2,748	690	138	
A 203......	Tangential.	170	264	12	2	47.8	4.08	2,375	583	142	Resoaked. Kiln-dried as No. 6 for 26 days; then soaked for 27 days from May 18. (The water-soaked portion was only the skin, $\frac{1}{16}$ to $\frac{1}{8}$ inch deep, which was cut off from the disks before weighing.)
B 203......		197	292	30	13	39.8	4.00	2,500	625	160	
B 223......		207	285	30	5	33.7	2.98	2,350	591	162	
B 243......		204	289	25	8	34.1	4.10	2,175	531	165	
C 203......		175	272	17	3	41.1	4.06	2,225	553	140	
L 203......		165	268	15	2	45.8	3.98	1,890	475	134	
M 203......		192	270	24	4	37.1	3.92	2,730	698	155	
O 203......		210	297	17	4	36.7	4.08	2,350	576	164	
Average.	....	190	208	21	5	39.5	4.02	2,324	579	153	

TABLE 10.—*Longleaf pine, shearing.*

For lumber see note for compression tests, Table 1. Kept damp in long strips. Cut to 3-inch lengths August 27, 1903.

No. of test piece.	Kind of shear.[a]	Weight when cut (3 inches long).	Weight at test (trimmed piece).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and moisture.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq. in.*	*Lbs.*	*Lbs. per sq. in.*		
201.........	T.	118	127	23	7	34.2	4.00	3,360	840	......	Soaked. Soaked in water 13 days, then dried off in the sun and tested.
211.........	T.	129	145	22	8	36.0	4.18	2,950	706	......	
221.........	T.	139	144	20	3	39.9	3.72	3,620	973	......	
231.........	T.	183	178	14	2	26.8	3.94	5,255	1,332	......	
241.........	T.	189	182	7	1	26.3	3.94	2,300	584	......	
251.........	R.	134	145	28	56	32.0	5.00	4,350	870	......	
261.........	R.	139	150	16	32	37.3	3.98	4,320	1,085	......	
Average .	....	147	153	18.6	.....	33.2	4.11	3,736	913	......	
202.........	T.	116	106	28	4	20.6	4.00	3,420	855	0.59	Green. Tested directly after keeping damp 4 days.
212.........	T.	122	145	21	6	20.0	4.00	3,480	870	.62	
222.........	T.	142	127	19	4	23.2	4.00	4,090	1,022	.70	
232.........	T.	178	161	18	3	22.5	4.00	4,770	1,192	.89	
242.........	T.	187	168	7	2	21.5	4.00	4,030	1,007	.95	
252.........	R.	135	125	26	52	23.2	4.00	4,240	1,060	.69	
262.........	R.	142	130	16	29	23.5	4.00	4,155	1,034	.72	
Average .	....	146	137	19.1	.....	22.0	4.00	4,023	1,006	.737	
202_1.......	R.	116	106	25	50	20.7	4.00	3,570	892	.59	Green. Same as last. Opposite kind of shear.
212_1.......	T.	122	112	21	8	20.3	4.00	3,740	935	.62	
222_1.......	R.	143	128	18	37	24.5	4.00	4,600	1,150	.71	
232_1.......	R.	175	160	18	36	22.3	4.00	4,360	1,090	.89	
242_1.......	R.	184	168	7	14	......	4.00	4,700	1,175	.93	
252_1.......	T.	132	125	27	6	19.9	4.00	4,800	1,195	.68	
262_1.......	T.	141	130	15	9	23.8	4.00	4,090	1,022	.72	
Average .	....	145	133	18.7	.....	21.9	4.00	4,266	1,066	.734	
203.........	T.	116	103	22	3	18.5	3.96	3,540	895	......	Partly air-dry. Dried in air of room for 9 days.
213.........	T.	124	110	21	5	19.2	3.94	3,955	1,000	......	
223.........	T.	141	120	18	3	19.7	3.70	3,025	818	......	
233.........	T.	174	153	18	4	19.2	3.94	4,665	1,182	......	
243.........	T.	181	161	8	2	20.8	3.92	4,170	1,063	......	
253.........	R.	134	120	28	57	18.5	3.94	4,715	1,195	......	
263.........	R.	142	......	17	34	21.0	3.94	4,435	1,125	......	
Average .	....	145	128	18.8	.....	19.6	3.91	4,072	1,040	......	
204.........	T.	115	90	20	4	13.2	3.70	4,200	1,135	......	Partly dry. Dried in kiln several days, then in air of room 5 days.
214.........	T.	125	101	22	3	13.5	3.98	4,765	1,195	......	
224.........	T.	141	110	18	2	14.1	3.88	5,250	1,352	......	
234.........	T.	173	140	18	0	13.9	3.92	5,900	1,504	......	
244.........	T.	180	148	8	0	14.6	3.82	4,740	1,240	......	
254.........	R.	134	108	28	56	13.6	4.56	7,000	1,535	......	
264.........	R.	143	113	17	34	14.3	3.90	6,010	1,542	......	
Average .	....	144	116	18.8	.....	13.9	3.97	5,409	1,358	......	
205.........	T.	115	95	22	3	......	......	......	......	......	Partly kiln-dried. Dried in kiln about 2 weeks at about 115° to 120° F.
215.........	T.	127	105	20	7	12.2	3.88	4,150	1,070	......	
225.........	T.	143	113	16	4	13.0	3.95	6,055	1,531	......	
235.........	T.	168	138	19	5	13.2	3.94	6,925	1,755	......	
245.........	T.	182	158	7	½	14.0	3.96	6,400	1,616	......	
255.........	R.	134	111	27	55	12.1	3.92	5,925	1,510	......	
265.........	R.	143	115	18	36	12.8	3.88	6,475	1,668	......	
Average .	....	145	119	18.4	.....	12.9	3.92	5,988	1,525	......	

[a] T=tangential; R=radial.

TABLE 10.—*Longleaf pine, shearing*—Continued.

No. of test piece.	Kind of shear.	Weight when cut (3 inches long).	Weight at test (trimmed piece).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and moisture.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr.ct.*	*Sq.in.*	*Lbs.*	*Lbs. per sq. in.*		
206	T.	119	93	......	.....	3.66	3.84	5,400	1,405	......	Kiln-dried. Kiln-dried in September, 1903, for about 2 weeks and again thoroughly dried in March, 1904.
216	T.	129	100	19	.....	2.91	3.84	5,110	1,330	......	
226	T.	143	107	17	.....	2.85	3.79	4,640	1,224	......	
236	T.	164	126	19	.....	2.65	3.91	6,880	1,760	......	
246	T.	185	147	......	.....	4.80	3.83	7,460	1,945	......	
256	R.	134	104	29	58	3.29	3.84	9,580	2,490	......	
266	R.	141	108	......	34	3.67	3.81	8,160	2,140	......	
Average	....	145	112	21	.....	3.40	3.84	6,747	1,756	......	
207	T.	117	89	23	3	.65	3.79	5,000	1,320	0.54	Oven-dry. Dried in kiln, as No. 206, and then in oven at 208° F. for several days.
217	T.	131	98	21	4	.50	3.83	4,190	1,090	.59	
227	T.	142	102	14	5	.30	3.73	3,180	853	.65	
237	T.	162	119	......	1	.28	3.83	6,180	1,610	.71	
247	T.	187	128	6	.....	1.90	3.79	7,420	1,960	.85	
257	R.	135	100	29	58	.29	3.79	4,920	1,300	.53	
267	R.	141	102	16	35	.22	3.79	7,140	1,885	.66	
Average	....	145	105	18.1	.....	.59	3.79	5,433	1,431	.647	
209	T.	115	106	25	9	18.0	4	3,580	895	.59	Green. Same as No. 202; cut from opposite end of the series.
219	T.	130	......	24	9	20.3	4	3,800	950	......	
229	T.	142	129	18	2	23.2	4	4,190	1,022	.71	
239	T.	160	144	24	3	22.4	4	4,250	1,062	.80	
249	T.	206	188	9	3	21.4	4	5,310	1,327	1.04	
259	R.	138	127	26	53	22.9	4	4,225	1,056	.70	
269	R.	137	126	19	58	23.2	4	4,310	1,077	.70	
Average	....	147	117	20.9	.....	21.6	4	4,238	1,056	.649	

TABLE 11.—*Chestnut, shearing.*

For lumber see note for chestnut compression Table 4. Treated in 6-inch lengths unless otherwise noted.

No. of test piece.	Kind of shear.[a]	Weight when cut (6 inches long).	Weight at test (trimmed piece).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq. in.*	*Lbs.*	*Lbs. per sq. in.*		
201	T.	320	165	9	1	132	4.04	2,970	735	......	Soaked. Soaked in water for 18 days from May 24. (Five of the specimens sank in water; all were thoroughly wet.)
211	T.	322	163	13	2	124	4.02	2,670	664	......	
221	T.	330	164	9	2	137	4.00	3,000	750	......	
231	T.	302	160	8	3	137	3.98	2,250	565	......	
241	R.	340	167	8	17	142	3.98	2,850	717	......	
251	R.	402	194	7	14	137	4.02	3,000	746	......	
261	R.	375	185	8	15	142	4.10	3,015	736	......	
271	R.	384	187	7	13	142	4.06	3,440	848	......	
281	T.	392	187	7	2	142	4.04	3,060	757	......	
291	R.	364	182	5	11	128	4.06	2,975	733	......	
Average	....	353	175	8	......	136	4.03	2,923	725	......	
202	T.	321	152	8	2	107	3.90	2,840	729	0.81	Green. Tested directly.
212	T.	322	152	13	2	103	3.84	2,875	743	.83	
222	T.	322	150	8	1	118	3.86	2,425	628	.84	
232	T.	307	150	8	1	189	3.84	2,415	630	.79	
242	R.	336	154	8	16	128	3.86	2,925	758	.88	
252	R.	402	183	7	14	124	3.88	2,865	739	1.02	
262	R.	366	174	8	16	126	3.90	3,185	817	.93	
272	R.	380	172	7	14	125	3.89	3,060	787	.97	
282	T.	395	180	8	3	123	3.90	3,350	860	1.01	
292	R.	357	169	5	9	105	3.86	2,800	726	.91	
Average	....	351	164	8	......	125	3.87	2,874	742	.899	
203	T.	......	97	9	1	22.1	3.99	2,350	590	......	Damp. Dried in kiln with steam at 130° to 140° F. for 11 days, then immersed in water 5 hours and put in damp box for 29 days. Cut to 3-inch lengths on the eighth day of drying. The wet spot in the center had disappeared.
213	T.	......	99	13	3	22.1	3.91	2,655	679	......	
223	T.	335	89	8	1	20.0	3.86	2,625	680	......	
233	T.	300	92	9	2	21.7	3.86	2,700	700	......	
243	R.	339	95	8	17	22.4	3.95	2,750	697	......	
253	R.	402	117	8	15	23.3	3.93	2,855	726	......	
263	R.	379	109	8	15	20.0	3.95	2,565	650	......	
273	R.	380	108	7	14	21.5	3.99	2,860	718	......	
283	T.	396	107	7	1	20.5	3.93	2,925	745	......	
293	R.	354	108	5	10	20.6	3.99	2,600	652	......	
Average	....	361	102	8	......	21.4	3.94	2,689	684	......	
204	T.	......	79	8	2	10.5	3.86	3,375	875	......	Partly kiln-dried. Dried in kiln with steam at 130° to 140° F., and humidity of 75 to 80 per cent, drier over night, for 21 days. Then stood in room for 2 days. (The wet spot in the middle had almost disappeared. Outer surface was trimmed off the discs before weighing.)
214	T.	320	78	13	2	11.7	3.82	3,475	908	......	
224	T.	339	75	8	2	10.2	3.82	2,940	770	......	
234	T.	288	73	10	2	10.0	3.76	3,195	850	......	
244	R.	233	78	8	17	10.4	3.96	4,200	1,060	......	
254	R.	402	95	7	14	13.5	4.02	3,845	957	......	
264	R.	382	84	8	15	7.4	3.98	4,725	1,190	......	
274	R.	380	88	7	14	15.0	4.00	3,095	775	......	
284	T.	399	92	8	3	12.8	3.88	4,485	1,155	......	
294	R.	......	89	5	10	11.8	3.94	4,375	1,110	......	
Average	....	343	83	8	......	11.3	3.90	3,771	965	......	
205	T.	334	72	8	3	2.1	3.75	3,000	800	.44	Kiln-dry. Kiln-dried for 33 days same as last in 6-inch lengths, then cut to 3 inch and kept in dry heat of 140° F. for 12 days.
215	T.	322	71	13	1	1.5	3.74	3,390	907	.45	
225	T.	338	69	9	1	2.5	3.74	2,660	712	.43	
235	T.	288	67	10	2	2.2	3.78	2,875	760	.41+	
245	R.	315	68	10	20	5.5	3.88	3,740	965	.43	
255	R.	365	77	9	18	2.3	3.86	4,075	1,055	.48	
265	R.	375	80	5	11	2.4	3.92	3,050	778	.51	
275	R.	395	79	6	12	2.3	3.92	3,325	849	.48	
285	T.	402	81	7	2	2.2	3.74	5,065	1,350	.50	
295	R.	350	82	7	13	2.2	3.90	4,000	1,030	.51	
Average	....	348	75	8	......	2.5	3.82	3,518	921	.464	

[a] T = tangential; R = radial.

TABLE 11.—*Chestnut, shearing*—Continued.

No. of test piece.	Kind of shear.	Weight when cut (6 inches long).	Weight at test (trimmed piece).	Rings per inch.	Rings sheared across.	Moisture.	Area of shear.	Total shearing load.	Shearing strength.	Specific gravity.	Conditions and treatment.
1	2	3	4	5	6	7	8	9	10	11	
		Grms	*Grms*			*Pr. ct.*	*Sq.in.*	*Lbs.*	*Lbs. per sq. in.*		
206	T.	335	71	8	2	1.0	3.71	3,115	838	0.44	Oven-dry. Kiln-dried as No. 204 then with dry heat for 4 days at 140° F. Placed in oven at 203° to 208° F. for 3 days. The last five were subjected to a vacuum of 26 inches and 210° F. during the last day.
216	T.	324	71	11	1	0.9	3.69	3,170	860	.44	
226	T.	321	69	8	2	0.6	3.73	2,845	763	.43	
236	T.	293	64	9	1	0.5	3.65	3,585	984	.40	
246	R.	313	66	11	22	0.5	3.79	4,080	1,080	.42	
256	R.	373	77	7	15	1.0	3.82	4,315	1,130	.47	
266	R.	266	81	5	11	1.0	3.86	3,790	982	.49	
276	R.	375	83	5	10	0.9	3.86	4,800	1,240	.50	
286	T.	204	80	7	2	0.8	3.81	4,755	1,250	.49	
296	R.	357	82	5	11	0.8	3.87	4,045	1,045	.49	
Average	....	316	74	8	......	0.8	3.78	3,850	1,017	.457	
REABSORPTION.											
207	T.	339	84	8	2	19.1	3.88	3,000	774	......	Reabsorbed. Kiln-dried for 35 days the same as No. 205, then placed in damp closet for 22 days.
217	T.	325	84	9	3	19.7	3.90	2,765	708	......	
227	T.	330	83	9	2	19.5	3.92	2,650	677	......	
237	T.	315	84	10	3	21.4	3.96	2,375	600	......	
247	R.	307	79	11	23	20.6	3.91	3,000	767	......	
257	R.	368	94	7	14	21.2	3.96	2,725	688	......	
267	R.	380	98	6	11	(20.8)	(3.98)	(1,650)	[a](414)	......	
277	R.	382	98	5	11	(21.0)	(3.93)	(1,875)	[a](477)	......	
287	T.	403	94	7	3	18.4	3.90	4,300	1,100	......	
297	R.	370	97	6	12	19.7	3.91	3,450	884	......	
Average	....	352	90	8	......	20.0	3.92	3,033	775	......	
208	T.	317	100	10	1	36.9	3.98	2,625	660	......	Resoaked. Kiln-dried for 35 days the same as No. 205, then soaked in water for 29 days from July 1.
218	T.	324	115	10	3	52.2	3.90	2,295	589	......	
228	T.	324	99	8	2	41.2	3.92	1,985	506	......	
238	T.	307	104	9	3	39.1	3.90	2,340	600	......	
248	R.	345	99	8	17	39.1	3.91	2,540	650	......	
258	R.	407	122	6	13	40.4	3.95	2,300	583	......	
268	R.	374	114	7	14	42.8	3.98	2,150	540	......	
278	R.	388	119	6	13	47.4	3.96	2,125	537	......	
288	T.	386	114	4	9	45.3	3.94	3,075	780	......	
298	R.	365	122	7	8	36.9	3.90	2,810	721	......	
Average	....	354	111	8	......	42.1	3.93	2,425	617	......	

[a] Nos. 267 and 277 sheared through the middle of the block, and therefore are not included in the averages.

COMPRESSION AT RIGHT ANGLES TO GRAIN.

(Table 12.)

The tests of compressive strength in a direction at right angles to grain may be made in two ways: (1) With the load acting over the entire area of the test piece, or (2) with the load concentrated over a portion of the area. The latter is the condition more commonly met with in practice, as, for example, where a post rests upon a horizontal sill, but the former is the one which gives the true resistance of the grain to simple crushing. The longleaf pine tests were made in the former manner upon 2-inch cubes, but the moisture records were destroyed in the fire and it was not thought desirable to repeat them, since this kind of test is of minor importance compared with the others. Five series of spruce tests were completed in the second manner. The test pieces were about 2 by 2 inches square and 12 inches long. These were laid horizontally upon the platform of the Olsen machine and a steel plate with square edges laid across the middle portion, covering 4 inches along the stick, or 8 square inches of surface. The load was applied at the same speed as for the bending tests, namely, about 0.1 inch per minute, and readings were taken at four points of deformation, corresponding to 3, 5, 8, and 15 per cent of the thickness of the test piece. The usual measurements and weights were recorded.

TABLE 12.—*Spruce, compression at right angles to grain; size 2 by 2 by 12 inches; compression area 2 by 4 inches.*

For lumber see note for spruce, Table 3. Treated in 12-inch lengths, except No. 302_1, etc., in 4-inch lengths.

No. of test piece.	Weight when cut (12 inches long).	Weight at test (12 inches long).	Rings per inch.	Moisture.	Area under compression.	Total load, at per cents of deformation. 3 per cent.	5 per cent.	8 per cent.	15 per cent.	Specific gravity	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
	Grms	Grms		Pr. ct.	Sq. in	Lbs.	Lbs.	Lbs.	Lbs.		
301	345	425	11	41.8	8.12	3,310	3,780	4,230	5,030	......	Soaked. Soaked in water for 28 days from Feb 16.
311	352	456	26	51.1	8.08	3,180	3,550	3,830	4,440	......	
321	392	478	22	44.2	8.12	4,440	4,860	5,260	6,200	......	
341	383	490	15	46.6	8.12	4,420	4,700	5,290	6,180	......	
351	414	504	12	42.3	8.08	4,130	4,590	5,140	6,000	......	
Average	377	471	17	45.2	8.10	3,896	4,296	4,750	5,570	......	
302	360	358	17	24.8	8.00	4,000	4,460	4,810	5,460	0.455	Green. Remained in damp box out doors all winter until tested.
312	346	352	20	26.4	8.00	4,140	4,580	5,030	5,750	.45	
322	452	419	....	35.1	8.00	3,890	4,220	4,630	5,200	.53	
342	385	384	15	26.2	8.00	5,100	5,430	6,170	7,240	.49	
352	373	367	15	24.8	8.00	4,930	5,340	5,840	6,770	.47	
Average	383	376	17	27.5	8.00	4,412	4,806	5,206	6,084	.478	
302_1	360	[a] 119	15	24.6	8.00	2,690	2,870	2,970	3,250	......	Green. Same as last. Cut 4 inches long and pressure applied over entire upper surface, showing effect of ends projecting in the other tests, by comparison with No. 302.
312_1	349	[a] 117	16	26.7	8.00	2,900	2,980	3,060	3,060	......	
322_1	430	[a] 135	37	32.1	8.00	2,550	2,730	2,810	3,090	......	
342_1	417	[a] 128	16	26.9	8.00	3,630	3,750	3,920	4,170	......	
352_1	379	[a] 122	14	25.0	8.00	3,470	3,520	3,600	3,880	......	
Average	387	124	20	27.1	8.00	3,048	3,170	3,272	3,490	......	
309	351	357	11	24.3	8.00	5,030	5,650	5,970	6,690	.45	Green. Same treatment as No. 302. Cut from the opposite end o the same series.
319	356	343	18	24.7	8.00	3,340	3,720	4,100	4,600	.44	
329	387	374	21	25.0	8.00	4,420	5,090	5,660	6,680	.48	
349	377	370	10	24.7	8.00	5,130	5,460	5,820	6,470	.47	
359	385	365	15	24.6	8.00	3,940	4,280	4,730	5,600	.46	
Average	371	362	15	24.7	8.00	4,372	4,840	5,256	6,008	.460	
303	352	312	13	10.8	7.68	6,670	7,300	8,290	(9,000)	......	Partly kiln-dried. Kiln-dried 22 days; with steam 17 days, cool at first, then raised to 100° to 120° F., followed by dry heat at the same temperature for 5 days.
313	357	308	26	10.1	7.60	7,250	8,170	8,500	(9,185)	......	
323	389	328	20	11.1	7.72	8,540	8,820	9,240	10,070	......	
343	388	330	....	10.5	7.64	8,500	9,110	9,950	11,050	......	
353	403	334	13	10.4	7.64	8,500	9,100	10,540	11,920	......	
Average	378	322	18	10.6	7.66	7,892	8,500	9,304	10,245	......	
306	356	301	14	5.5	7.60	7,970	8,510	9,510	10,580	......	Nearly kiln-dry. Same as last, except dry heat for 14 days.
316	330	272	26	4.7	7.52	7,160	8,220	8,810	9,800	......	
326	380	308	19	5.2	7.56	8,400	8,980	9,420	10,630	......	
346	457	328	14	5.2	7.48	9,800	10,700	10,800	12,435	......	
356	390	317	14	5.7	7.52	8,600	9,670	10,330	11,500	......	
Average	383	305	17	5.3	7.54	8,386	9,216	9,774	10,989	......	
307	354	297	10	4.7	7.60	8,850	9,550	10,800	11,800	.41	Kiln-dry. Same as No. 303, except dry heat for 40 days.
317	329	276	25	4.7	7.72	7,500	8,175	9,100	10,200	.37	
327	383	309	21	4.6	7.68	10,000	10,750	11,300	12,500	.42	
347	425	324	12	4.8	7.48	10,500	11,700	12,400	13,600	.45	
357	379	305	11	5.0	7.60	9,100	10,250	11,600	13,400	.42	
Average	374	302	16	4.8	7.62	9,190	10,085	11,040	12,300	.414	
307_1	355	294	13	2.6	7.60	8,270	9,410	10,150	11,720	.40	Oven-dry. Same as No. 303, except dry heat for 2 months, and then dried in oven at 208° F. during daytime for several days.
317_1	340	273	22	2.3	7.60	6,620	8,050	8,670	9,480	.38	
327_1	424	312	30	3.0	7.44	9,000	9,700	9,880	10,970	.44	
347_1	390	319	21	2.7	7.64	8,300	9,430	10,280	11,800	.44	
357_1	377	298	13	2.5	7.45	5,700	8,120	9,420	11,440	.42	
Average	377	299	20	2.6	7.55	7,578	8,942	9,680	11,082	.416	

[a] 4 inches long.

TABLE 12.—*Spruce, compression at right angles to grain; size 2 by 2 by 12 inches; compression area 2 by 4 inches*—Continued.

REABSORPTION.

No. of test piece.	Weight when cut (12 inches long).	Weight at test (12 inches long).	Rings per inch.	Moisture.	Area under compression.	Total load, at per cents of deformation. 3 per cent.	5 per cent.	8 per cent.	15 per cent.	Weight when kiln-dry.	Condition and treatment.
1	2	3	4	5	6	7	8	9	10	11	
	Grms	*Grms*		*Pr. ct.*	*Sq. in*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Grms*	
304.........	353	423	....	32.7	8.12	3,100	3,420	3,730	4,160	297	Resoaked. Kiln-dried 2 months as No. 307, then stood in room 14 days and soaked for 32 days from May 2.
314.........	346	426	23	41.1	8.24	3,370	3,600	3,980	....	285	
324.........	448	471	....	30.9	8.04	3,300	3,750	4,150	....	325	
344.........	390	528	14	55.1	8.04	3 950	4,270	4,820	5,750	319	
354.........	388	444	15	31.6	8.12	3,360	3,870	4,300	5,050	315	
Average .	385	458	17	38.3	8.11	3,416	3,782	4,196	....	308	
308.........	360	370	22	27.9	8.04	3,375	3,675	3,975	4,570	298	Reabsorbed. Kiln-dried 2 months as No. 307, then stood in room for 52 days, placed in cool, condensed steam 2 days and damp box for 40 days.
318.........	344	357	22	29.1	8.12	3,140	3,375	3,750	4,150	287	
328.........	384	385	18	27.9	8.16	4,825	5,175	5.545	5,890	309	
348.........	440	499	10	53.9	8.16	3.900	4,250	4,675	5,425	319	
358.........	388	392	12	28.8	8.16	4,000	4,425	4,850	5,690	315	
Average .	383	401	18	33.5	8.13	3,848	4,180	4,559	5,145	306	

In compression at right angles to grain no ultimate maximum point is reached, but the load gradually increases irregularly as the fibers are pressed closer and closer together. With projecting ends, as in these tests, there is sometimes a slight sudden falling off of the load where the projecting ends split horizontally. The reason for this is plain when the manner of failure is considered, the fibers collapsing a few at a time, beginning with those with the thinnest walls.

Compression in the tangential direction shows much greater strength and stiffness than in the radial direction, as would naturally be expected.[a] All the spruce tests were made in the radial direction.

If there are no ends projecting, the strength will be, of course, simply that of the material directly beneath the steel block. As the ends are allowed to project more and more, a beam action enters in which helps support the load, but beyond a certain point there is no further advantage gained in lengthening the ends. Experiment showed that this occurred at about 4 inches in length for the specimens used. The results, although expressed as pounds per square inch, evidently do not apply to pieces indiscriminately, on account of the influence of the ends, but they do apply to pieces of whatever width, compressed by a block with square edges covering 4 inches along the grain and with ends projecting 4 inches or more (see Table 13, p. 65).

[a] In the case of such woods as oak, having large medullary rays, the opposite of this is true.

TABLE 13.—*Effect of the projecting ends in increasing the strength of green spruce compressed at right angles to grain.*

	Load per square inch in pounds at deformation of—			
	3 per cent.	5 per cent.	8 per cent.	15 per cent.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*
With 4-inch ends	551	601	662	760
Without projecting ends	383	396	408	437
Increase in strength due to ends	43.8%	51.8%	62.3%	73.8%

MOISTURE DETERMINATIONS.

Since the whole question of the influence of moisture upon strength is based upon the moisture content of the wood, it is of the first importance to determine accurately this moisture content. To dry out the entire specimen after testing and then ascertain its loss in weight would not only be difficult, but would give incorrect results, for two reasons: First, because it would be practically impossible to get a large block absolutely dry, and, second, because there would be nothing to show the amount of moisture at the point where the break occurred. The "disk method" has proved to be the most satisfactory and was the one used. With this method a narrow cross section of the piece is cut out by a smooth-cutting circular saw at the point where the failure occurred. This is at once weighed, and subsequently dried in the drying oven at the boiling temperature until no more loss in weight occurs, when the final weight is recorded. The loss in weight multiplied by 100 and divided by the dry weight gives the per cent of moisture based upon dry weight. All moisture per cents here given are thus based upon dry weight unless otherwise stated. Of course this does not render the disks absolutely dry, but if all the pieces be treated in the same way it serves as a correct basis of comparison.

In order to show just how much moisture remains in the disks after being dried in this manner, a number of them were completely dried in a vacuum oven, where they were subjected to a high vacuum at a temperature just below the boiling point of water, with circulation of previously dried air. The amount of moisture remaining in the disks is perceptible, as will be shown, but not enough to disqualify the method of test described above.

Experiment indicated that the boiling point was a suitable temperature, as well as the most convenient one, at which to conduct the drying operations.

Usually three moisture disks were taken from each specimen, but sometimes four. Disk *a* was cut so as to include a portion of the

failure; *c* was taken at a distant point in order to show the distribution of moisture lengthwise in the specimen. In beams disk *a* was taken at about 9 inches from the center; in the compression blocks, on the end when failure occurred in the middle, or in the middle when it occurred on the end.

Disks *a* and *b* were three-fourths of an inch in thickness for longleaf pine, and 1 inch for the other species. A third disk, *c*, of half the thickness, was cut adjacent to *a* (or to *b* if *a* were much split up). This disk *c* was for the purpose of calculating any loss from the two surfaces during the process of sawing,[a] and it also served as a valuable check upon the other moisture disk. The loss was found to be imperceptible for disks half an inch or more in thickness, and so disk *c* was sometimes omitted.

Another disk, designated as disk *x*, was cut of the same thickness as disk *a* and adjacent to it (or to *b*, if *a* were much split up). This was taken for at least three specimens out of each set and was cut up transversely, so as to obtain an outer layer about one-fourth inch deep and a central piece about three-fourths inch square, the intermediate portion being discarded. By weighing outer and inner portions separately and calculating their respective moisture per cents, the radial distribution of moisture in the specimen was obtained.

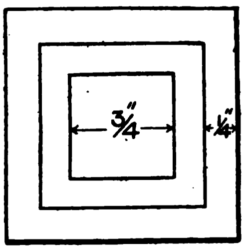

FIG. 4.—Disk *x* for determining radial moisture content.

As a rule, the outer portion was found to be somewhat drier than the inner. If this difference in moisture distribution be considerable, it will affect the shape of the curve, as explained on page 18, especially in the bending tests, and must be taken into consideration.

The aim was always to have the moisture evenly distributed, but it is often impossible to obtain this condition perfectly.

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[a] Credit for this method of obtaining the loss of moisture in sawing is due to Mr. Loren E. Hunt, of the Forest Service. The calculation is as follows:

Let W_1 (thin disk) and W_2 (thick disk) = weights of disks when first cut.
G_1 (thin disk) and G_2 (thick disk) = weights of disks when dry.
P_1 (thin disk) and P_2 (thick disk) = per cent moisture in disk ÷ 100

And let L = loss in weight from surfaces during sawing
P = per cent of moisture in disk before sawing ÷ 100

Then: $$L=\frac{W_1G_2-W_2G_1}{G_1-G_2}$$

And $$P=\frac{(W_1-G_1)-(W_2-G_2)}{G_1-G_2} \text{ or } \frac{P_1G_1-P_2G_2}{G_1-G}$$

For the shearing tests no disks were cut, but the tenon sheared off was used in place of a disk. With some of the soaked pieces the outer surface of this tenon was trimmed off before weighing, thus giving the moisture at the shearing surface.

The disks were cut by a smooth-cutting circular saw, and weighed at once. All the weighings were made to the nearest centigram upon a fine chemical balance, giving four significant figures in the weight.

THE DRYING PROCESS.

For drying the disks there is a copper oven completely jacketed with water and steam, except for two doors in front. The material to be dried is placed within, upon three wire-netting shelves, and proper circulation of air is obtained through ventilators in the bottom of the door and the roof of the oven. The oven, which measures 20 by 20 by 24 inches inside, is heated by gas heaters from below. The temperature inside may be maintained very near the boiling point, or about 208° F.

For more complete drying a smaller cylindrical jacket oven, 6 inches in diameter inside by 16 inches long, was used, in which a partial vacuum was maintained during the drying by means of a filter pump attached to a hydrant. A circulation of dry air was obtained by suction through two Woulff's bottles, containing concentrated sulphuric acid. The circulation was regulated by a stopcock. In this oven a temperature of 206° F. and a vacuum of 24 inches may be maintained.

The longleaf pine disks were first dried at 176° F. to constant weight, requiring about eight or ten days, and then at 208° F. for four or five days longer, in order to discover the best temperature for drying.[a]

In drying the longleaf pine disks it was found best to raise the heat gradually, keeping it below 140° F. until the resin which oozed out began to harden and dry up. Otherwise the resin exudes as a thin liquid and drips off.

The spruce and the chestnut disks dry very much more quickly, requiring 24 to 46 hours at the boiling temperature. In order to be on the safe side, however, they were dried twice this length of time.

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[a] The disks were weighed after remaining in the oven six days, and again after four more days. It was found that the ⅜-inch disks had not changed any in weight (except the extremely resinous ones) during the last four days, but that the ¾-inch disks had lost up to 0.24 gram, averaging 0.04 gram, during this period, and at the end the extremely resinous ones were still losing somewhat. This amount, however, is insignificant compared with the dry weight of the disk, which ranges from 30 to 40 grams.

The difference between drying at 176° and 208° F. for the longleaf pine averaged 0.6 per cent of the dry weight [a] (average of 94 disks).

The disks which were to be further dried in the vacuum oven just described were treated in the following manner:

The disk from the air oven was carefully sliced up by means of an ordinary tobacco knife, into layers scarcely thicker than shavings. These were put into small wire-gauze baskets of fine mesh and placed in the vacuum oven in such a way as to allow a free circulation of air. The loss in dust due to the shaving operation was found to be negligible. The shavings were dried in this oven for about five hours at 24 inches of vacuum and 208° F., then placed in a desiccator for a minute or two, or weighed immediately while hot.

The average difference in per cent of the dry weight (large oven) was as follows:

Longleaf pine	7 disks, 0. 6 per cent moisture.
Spruce	35 disks, . 78 per cent moisture.

In order to be exact, another factor must evidently be taken into account, namely, the loss of volatile oil and of other matters during the drying of the disks. Earlier experiments show that the loss of other materials below 212° F. is insignificant,[b] so that only the volatile oil need here be considered.

VOLATILE OIL DETERMINATIONS.

A detailed account of the process used in extracting the volatile oil will be found in the Appendix; suffice it to say here that these results bear out the conclusions arrived at by others. Mr. L. E. Hunt, in charge of the testing laboratory of the Forest Service at Berkeley, Cal., has shown conclusively that practically no loss of volatile oil

[a] In Circular 12 of the Division of Forestry, March 6, 1896, page 7, the following conclusions were given regarding the moisture remaining in the hard pines, when dried at different temperatures, assuming wood dried at 212° F. to contain no moisture.

Dried at 150° F., 1½ to 2 per cent remaining.

Dried at 175° F., 1 per cent remaining.

Dried at 212° F., 0 per cent remaining.

But as pine dried at 212° F. still contains 0.6 per cent moisture of the weight at 212°, the above figures become for (practically) absolute moisture:

Dried at 150° F., 2.1 to 2.6 per cent remains.

Dried at 175° F., 1.6 per cent remains.

Dried at 212° F., 0.6 per cent remains.

[b] Decomposition of sound pine wood in grams of CO_2 in one hour for each gram of wood, is given in the Proceedings of American Academy of Arts and Sciences as 0.00009 at 123° C., and 0.00020 of volatile matter. This would mean 0.000024 g. of carbon besides the volatile matter; or, not including the volatile matter, 0.0058 g. carbon in ten days per gram of wood. However, this temperature is considerably above that at which the disks were dried.

occurs in kiln-drying the wood, or even in drying the disks in an oven at 212° F.[a]

This being the case, there is no correction to be made in the moisture determinations for volatile oil. The average amount of oil in the longleaf pine, which is, including all losses, not over eight-tenths of 1 per cent of the dry weight of the wood, is evidently too small to take into account when considering the amount of moisture, even were most of it to evaporate in drying the disks. The amount contained in the spruce and chestnut is altogether insignificant. (Two specimens of spruce gave results of 0.05 and 0.06 per cent, respectively.)

METHODS OF CALCULATING AND DERIVING THE RESULTS.

THE CALCULATIONS.

In figuring the results of the tests the following plan was carried out: For the endwise compression and the cross-bending tests, stress and strain diagrams were plotted for each individual test upon cross-section paper, from the readings of loads and deflections recorded upon the test-record sheet. A straight line was drawn coinciding as nearly as possible with the straightest initial portion of the curve, and this line was extended downward to the zero load line, from which calculations for the modulus of elasticity and the elastic resilience were made. Calculations made in this way give the most reliable results, since accidental irregularities in the curve are eliminated, and the result is based on the average rate of deflection below the elastic limit, rather than upon a single set of readings. Moreover, differences at the beginning of the test, before the parts become fully adjusted, are done away with.

The elastic limit was also determined by this line, being taken as the point where the curve becomes tangent to it.

All measurements of area and the height and breadth of beams were made to the nearest hundredth of an inch, the deflections of the beams also to hundredths, and the deflections of compression to thousandths of an inch. Weights of test specimens were made in grams, and weights of disks to the nearest centigram. The calculations of the various strength factors were made in the usual way. The formulas are given in the Appendix, page 112.

The calculated results, as well as the various weights, dimensions, moisture content, etc., were all tabulated in systematic order upon large charts, abbreviated forms of which are given in Tables 1 to 12. The moisture records were also similarly tabulated on separate sheets.

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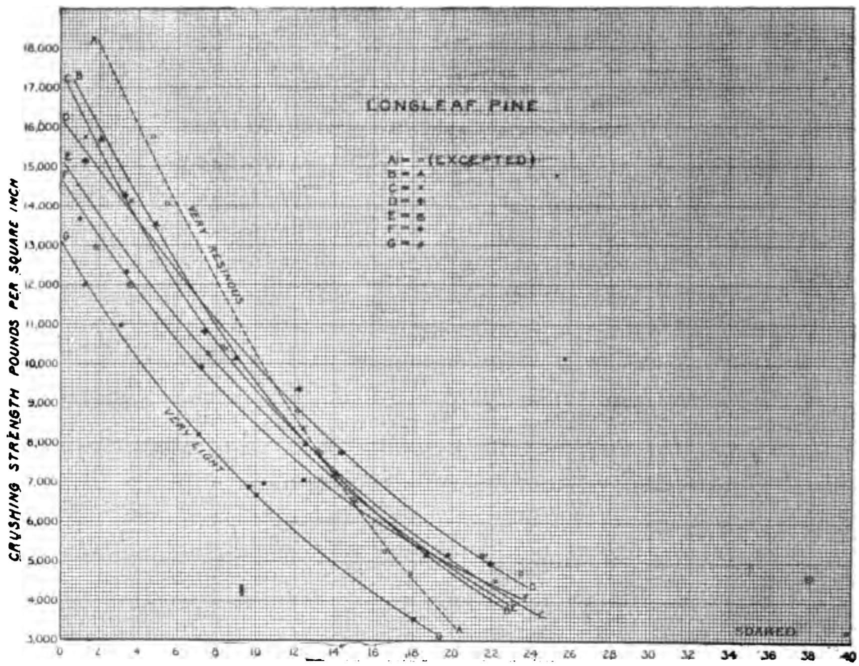
[a] See also an article by Dr. W. K. Hatt in the Proceedings of the Am. Soc. for Testing Materials, Vol. III, 1903, "A Discussion on the Effect of Moisture on Strength and Stiffness of Timber."

CORRELATING AND AVERAGING.

Having thus tabulated the individual results, it next remains to deduce the fundamental law for which we are seeking, by a proper correlating and averaging process, and to determine the degree of variability of the single specimen. This is best accomplished graphically.



MOISTURE—PER CENT OF DRY WEIGHT.

FIG. 5.—Individual moisture-strength curves for 7 series of longleaf pine, compression parallel to grain.

The chief strength factors whose moisture relations are to be determined for each of the three species are these:

(1) Compression strength parallel to grain.
(2) Modulus of elasticity in compression parallel to grain.
(3) Elastic limit in compression parallel to grain.
(4) Modulus of rupture in bending.
(5) Modulus of elasticity in bending.
(6) Stress at elastic limit in bending.
(7) Shearing strength parallel to grain.
(8) Compression strength at right angles to grain (for spruce only).

In addition to these, comparison of the strength factors of compression pieces cut from beams and special studies enumerated later on were made.

This makes 22 principal curves and corresponding tables, besides

various other comparative ones. For each of these groups[a] an average curve was obtained in the following manner:

All the individual points for the group in question were plotted upon cross-section paper, and a separate curve drawn for each moisture series, upon the same sheet of paper when practicable. When there were so many points as to cause confusion they were divided into

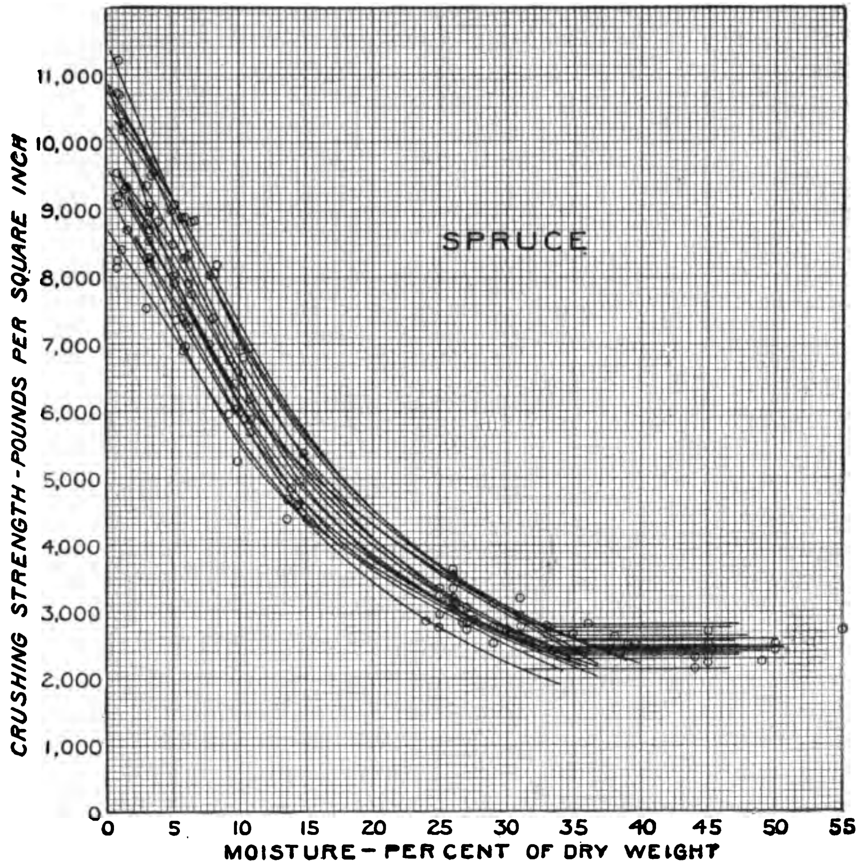


FIG. 6.—Individual moisture-strength curves for 16 series of spruce, compression parallel to grain.

groups and plotted on two or more sheets, to be subsequently combined. This was done with the spruce end compression tests, consisting of 16 series, which were plotted upon three separate sheets, to prevent confusion by undue overlapping of the points. (See fig. 6.) The series curves were drawn as smooth lines among the respective points by means of splines. The soaked points, which usually fell far out of line with the others, as already explained (p. 18), were discarded in drawing the curves. This stage of the process is

[a] Except the elastic limits for longleaf pine compression and beams, which were plotted, and a single curve drawn for each.

shown by fig. 5, which is the original plate for the longleaf pine compression curves. Sometimes a series was found to be too irregular to form a reliable curve and was discarded in the final average.

Having obtained the individual-series curves, these were then averaged together (the strength values being averaged for definite moisture per cent values) and the final average curve drawn through the points thus obtained.

This process of drawing separate curves for each series and then averaging these curves gives more reliable results than could be obtained by averaging the individual points directly; for the latter procedure would involve a cross averaging of moisture as well as of strengths, since the moisture per cents are not constant throughout each set. Plotting all of the individual points furthermore allows of better judgment in determining the position of each average curve.

The greatest variation, above and below, of any single point used in deriving the general average curve was calculated in percentage of the same and is given in Tables 18 to 20. In the same way, after 10 per cent of the total number of points falling farthest above, and the same below, had been counted out, the greatest variations of the remaining points, or 80 per cent of all points, both above and below, were reckoned, and are expressed in the tables.

In the case of longleaf pine an attempt was made to supplement the regular tests by determining the relation between dry specific gravities and strength. This was the only species in which the range in the weights of the series was wide enough for this purpose. The endwise-compression tests were, however, the only tests which showed a sufficiently regular variation of strength with dry weight to establish such a relation. Fig. 7 shows graphically the dual relation of moisture to strength and to specific gravity for longleaf pine in compression parallel to grain. The results were obtained by drawing a second set of curves, showing the relation of strength to dry weights for different given moisture per cents, the points being taken from the first curves, described above. Having thus harmonized the original curves in the direction of dry weights, a third and final plate was made, similar to the first, but taking its points from the lines of the second plate. In drawing the lines in the second plate, it is assumed that the strength varies directly with the dry weight.

The result is the series of curves given in fig. 7, and an empirical equation derived therefrom is given on page 88. The table derived in this manner from this plate reads harmoniously in both directions, as will be seen. (Table 21.) It should be noted that this is the most reliable process of deriving a compound table from variable data, since it gives due consideration to every figure in its proper relation, and indicates every irregularity in individual points. Hence any figure taken from this table is much more reliable than the original

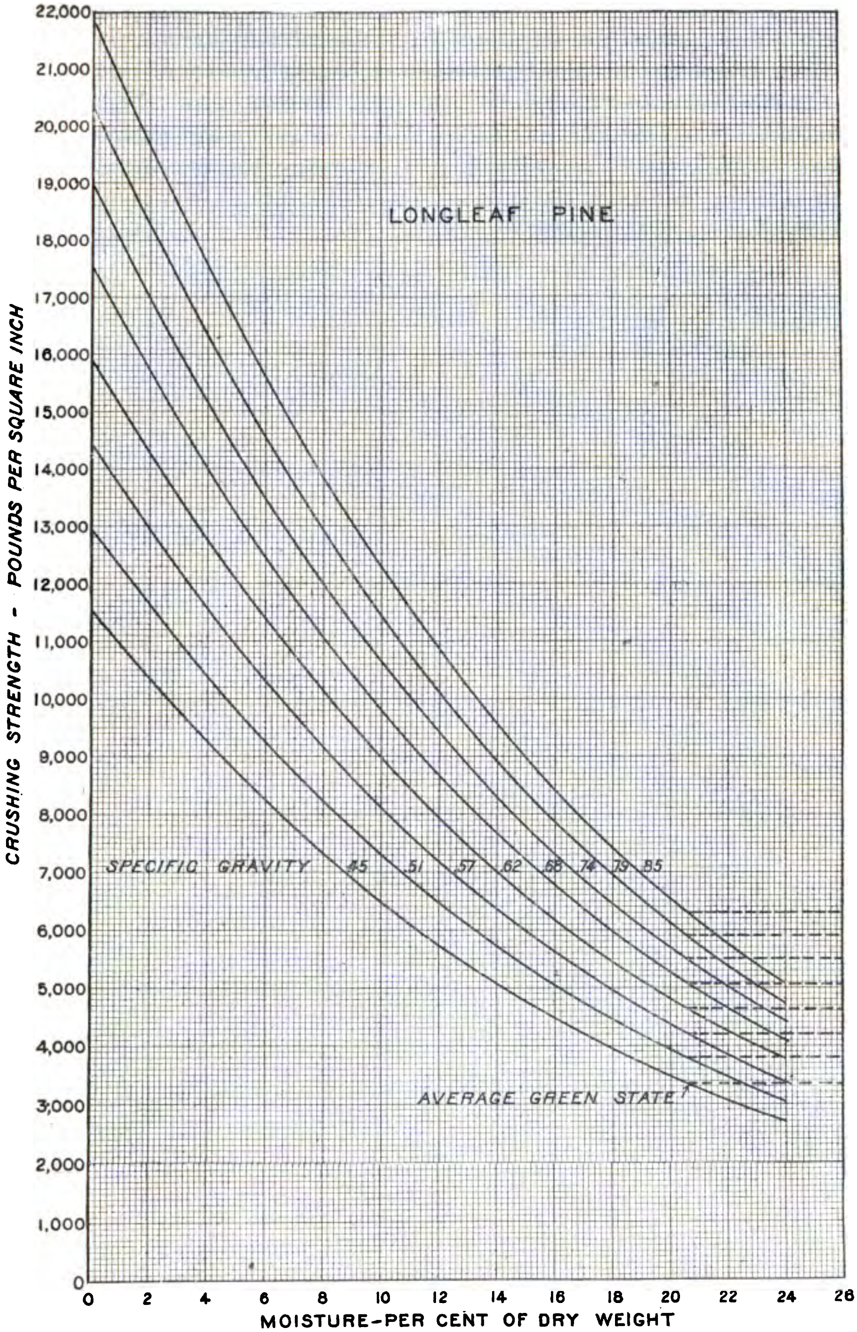


FIG. 7.—Strength of long-leaf pine harmonized for specific gravity and moisture. Compression parallel to grain.

test value, since it is now correlated to and based upon the entire collection of tests, instead of upon an independent value.

In calculating the values for beams, the assumption is made that the neutral axis passes through the center of the specimen. That this is not true at the point of rupture is perfectly evident, both theoretically, because the tensile strength exceeds the compression strength some three times, and from the appearance of the failure, the neutral axis falling far below the center line of the beam. This eccentricity of the

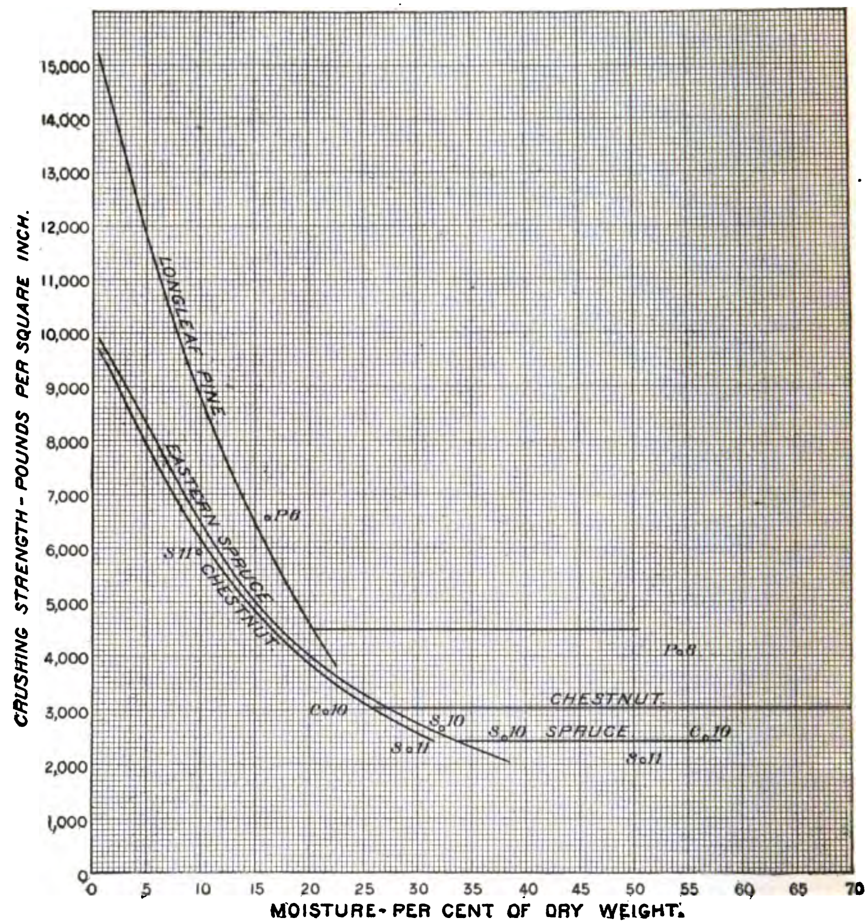


FIG. 8.—Variation of strength with moisture in compression parallel to grain.

neutral axis is shown in the result of the comparison of the calculated stress at elastic limit in bending with the ultimate crushing strength of pieces cut from them and tested the same day. (See Table 17, and figs. 9 and 16, in which the stress at elastic limit of the beams exceeds the crushing strength, especially in the green state.) In the dry state the elasticity or ratio of stress to strain in compression and tension appears to become more equal, and these curves are seen

to approach each other gradually until they coincide at the driest point. The calculated "modulus of rupture" for wooden beams is therefore, as Professor Johnson states, "a purely fictitious quantity and does not really represent any actual tensile or compressive stress on the extreme fibers at all. It may, however, be called the 'modulus of rupture in cross breaking' in pounds per square inch, and

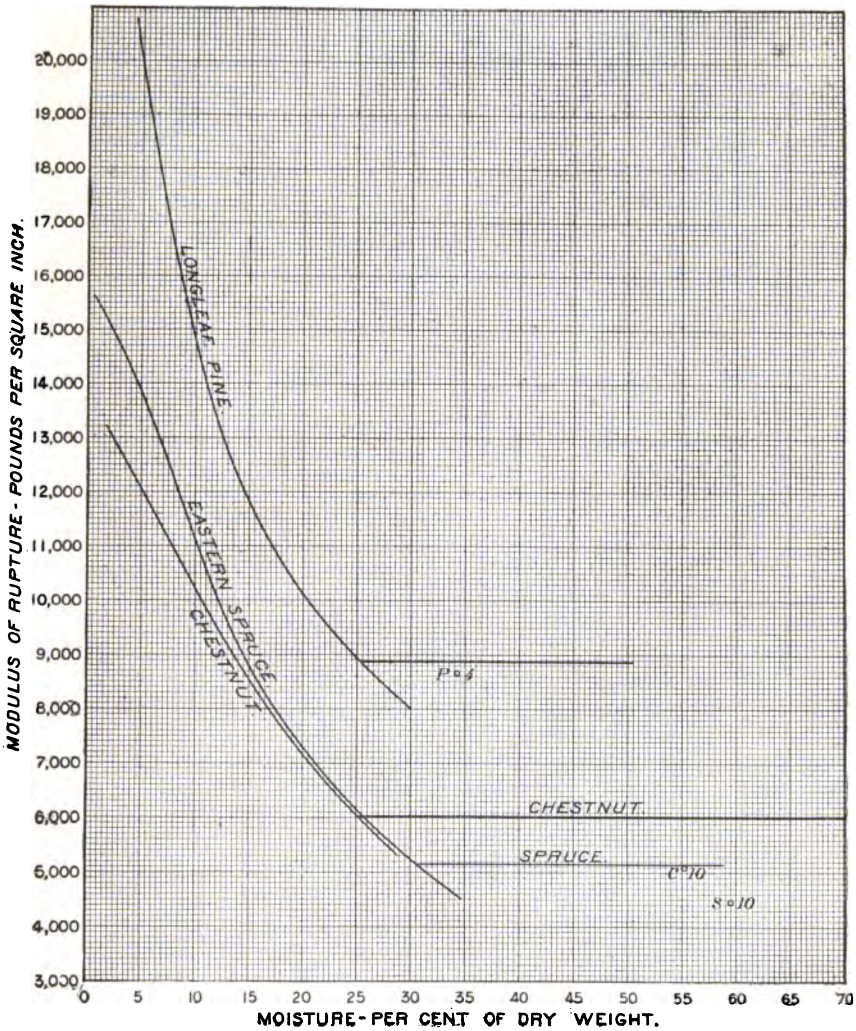


FIG. 9.—Variation of strength with moisture in bending.

used to indicate the strength of the material when loaded as a beam; but it must not be confused with or assumed to have any fixed relation to either the tensile or the compression strength of the material."

The strength, however, is proportional to the square of the depth, and the stiffness to its cube, whatever be the numerical expression used.

EFFECT OF SHRINKAGE.

All the calculations are based upon the actual measured dimensions of the pieces at the time of the tests, and not upon the size of the pieces

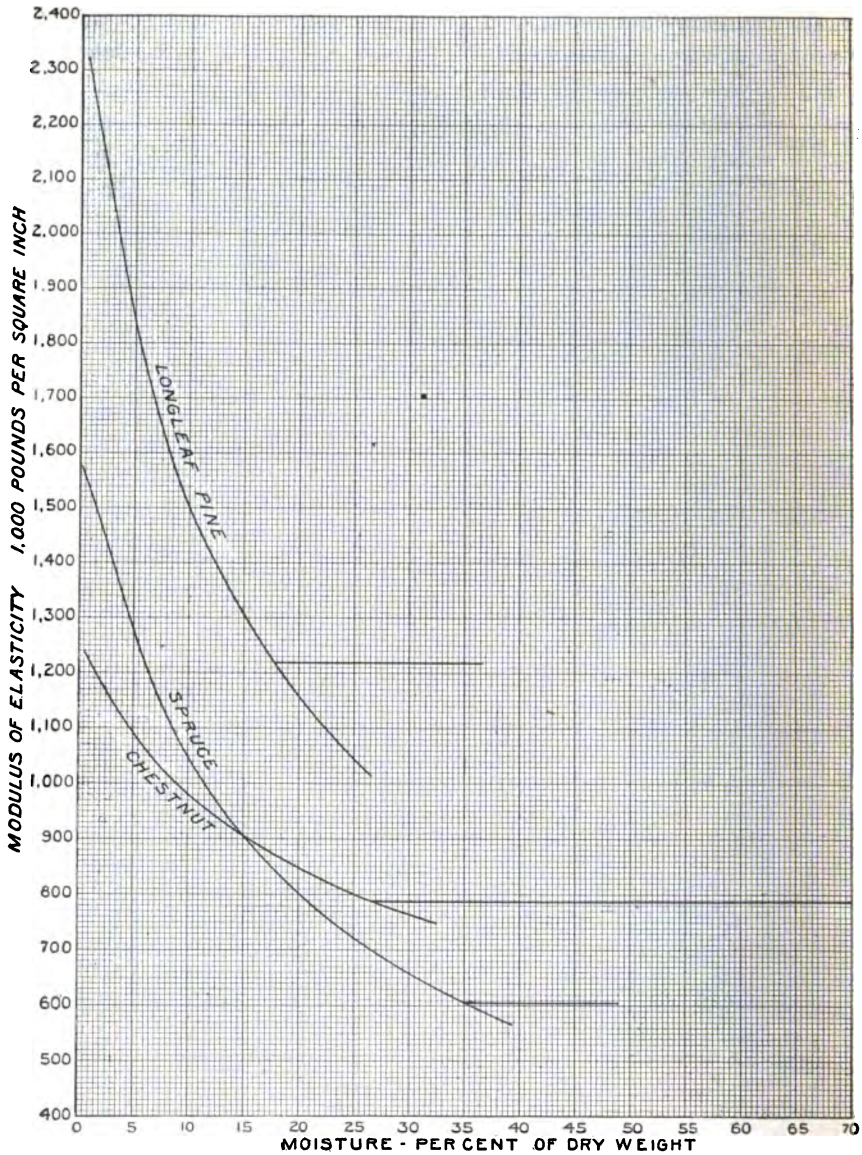


FIG. 10.—Variation of stiffness with moisture in compression parallel to grain.

when green. As there is a considerable shrinkage in drying, it is evident that a square inch of dry wood must contain more fibers than a square inch of wet wood. Hence it follows that the figures here given

show a more rapid increase in strength than would be shown if they were based upon the drying of the self-same piece. In other words, the figures in the tables show the strength of square inches at different degrees of moisture, but do not show the increase of strength of the

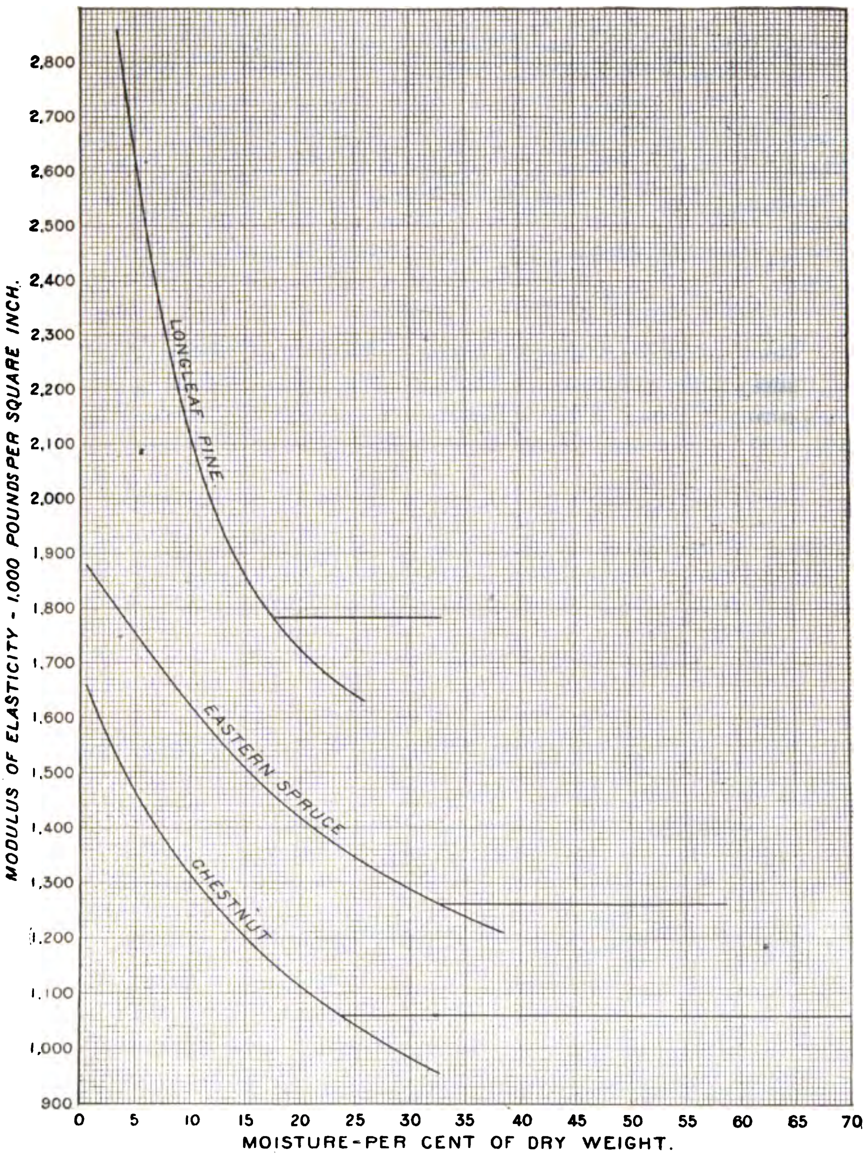


FIG. 11.—Variation of stiffness with moisture in bending.

selfsame piece during drying. To get the figures for the selfsame piece, the given ratio is to be multiplied by the reduction in cross-sectional area. Thus, if C_0 be the strength per square inch of green wood

and C the strength per square inch of dry wood, A_0 and A being their corresponding cross-sectional areas, then the given ratio is $\frac{C}{C_0}$ and the ratio of the amount the self-same stick would increase in strength from the green to the dry condition would be $\frac{C}{C_0} \times \frac{A}{A_0}$. For the modulus of elasticity in compression the same is true.

In the case of beams the shrinkage in area causes a consequent decrease in the resisting moment, which still further reduces the strength and stiffness. If h_0 and h are the heights when green and when dry, and b_0 and b the breadths, respectively, the ratios for the self-same beam may be found from the given ratios per square inch, as follows:

For modulus of rupture and fiber stress at elastic limit, multiply by $\frac{bh^2}{b_0h^2_0}$.

For modulus of elasticity multiply by $\frac{bh^3}{b_0h^3_0}$.

But this whole question of the loss in the strength of a specimen due to shrinkage in its dimensions is so enormously offset by the corresponding increase in the strength due to the drying of the wood, that, ordinarily, it is not worth considering.

The ratios $\frac{A}{A_0}$ affecting the strength and elasticity of the compression piece for the three species, between the green condition and when kiln-dried to 3½ per cent moisture, are, as an average, the following:

Longleaf pine	0.90
Spruce	.92
Chestnut	.90

The ratios $\frac{bh^2}{b_0h_0^3}$ affecting the strength of beams are, as an average:

Longleaf pine	0.88
Spruce	.89
Chestnut	.87

And the ratios $\frac{bh^3}{b_0h_0^3}$ affecting their stiffness:

Longleaf pine	0.85
Spruce	.86
Chestnut	.84

These, then, are the factors by which the figures given in the tables should respectively be multiplied, in order to answer the question as to how much the selfsame stick would increase in strength. For comparison, this result is given in column 16, Table 1.

The elastic resilience per cubic inch is calculated in the ordinary way from the diagram, beginning with the tangent line where it intersects the zero load line, and using the area of the triangle whose apex

is the elastic limit point on this tangent line. Algebraically it is proportional to $\frac{f^2}{E}$ where f is the fiber stress at elastic limit, and E is the modulus of elasticity. This is an extremely variable quantity, and no moisture curves for it have been drawn, although it necessarily increases as the other strength values increase.

The shearing stress is simply the total load divided by the area sheared off.

In calculating the compression at right angles to grain, the load was taken at 3, 5, 8, and 15 per cents deformation of the depth, as explained before, the area under compression being 2 by 4 inches, or 8 square inches, with projecting ends on either side of the steel block 4 inches long. Inasmuch as these ends as well as the material directly under compression influence the strength, it follows that the value so obtained, as reckoned per square inch, does not apply to other dimensions. It does, however, apply to other widths, since the influence of the ends would be the same whatever the width. One complete set was tested with the ends cut off, so that the entire piece was under compression, and the result given in Table 13 shows the effect of the ends in increasing the strength.

The resulting values, although expressed in pounds per square inch, apply only to pieces about 2 inches thick, but of any width, compressed by a block with square edges covering 4 inches in length along the grain, and with ends projecting at least 4 inches on either side.

TREATMENT ACCORDING TO SPECIES.

LONGLEAF PINE.

The material for the longleaf pine tests was procured in the New Haven market, from a firm dealing exclusively in this lumber. There were twenty 4 by 8 inch planks, and two 3 by 12 inch planks, 22 feet in length, of the best quality that could be obtained, although not without some knots and sapwood. The timber was said to have been cut and sawed in the spring of 1903 at Tifton, Ga., having grown in that vicinity. The material was in a thoroughly green condition when cut up for the tests.

Each plank was marked, cut up into long strips, and these planed to 2 by 2 inch size. Beginning with one end, the strips were then divided into consecutive lengths to correspond to the specimens required, imperfect pieces being culled. The specimens were given reference numbers which indicated the position which they occupied in the planks from which they were cut.

The specimens were carefully selected from the strips according to grain. Pieces for the beam tests were cut into 42-inch lengths, and for the end compression tests into 8-inch lengths, the latter

being trimmed to exactly 6 inches at time of testing, as already explained. In the beam tests the specimens in the same series were not always taken from the same plank. In both beam and compression tests the specimens were cut so as to have the rings diagonal to the cross section. All the specimens were photographed before being tested, and representative sets after being broken to show the kind of failure. These photographs are on file together with the original tables, curves, and test records.

The tests were performed and the results calculated in the manner already explained.

There were seven series of end compression, seven of bending, and seven of shearing tests, five of the last being tangential and two radial. Series No. 7 of the compression tests was abnormally resinous (page 26) and the results were discarded in the average; and series 3 and 7 of the beams were so irregular that they were also discarded in the final averages. Of the shearing tests, several series were too irregular to form curves and were discarded. The irregularity of the latter kind of tests has been discussed on page 62.

SPRUCE.

The spruce material for five series of compression at right angles to grain, five series of compression parallel to grain, and eight series of shearing tests, was selected in the market and procured in 3-inch planks September 22, 1903. That for the remainder of the tests, namely, twelve bending series, eleven end compression, and eight shearing, was obtained from the same place in March, 1904, in 3 by 12 inch planks. Both lots were fresh cargoes from a mill at St. John, New Brunswick, and were cut in the forests of northern Maine. The former lot of specimens was prepared in November, 1903, together with other series sufficient to complete the study. A fire in December of that year, however, broke up all the other series of 1903 than the ones mentioned. These were in a tight, zinc-lined box outdoors, and remained there until February 17, when they were taken out and put under the proper treatment prior to testing. The specimens had dried out about 3 per cent in weight during this time.

The foregoing record of the series of 1903 is given thus in detail because of the apparent effect it had upon the modulus of elasticity of the end compression tests. As stated before, the modulus of elasticity appears to be easily affected by extrinsic conditions, and in this case the end compression tests showed a remarkable loss in value for the modulus, as compared with the freshly prepared material, the ratio of the two values being, as an average, 0.614. The cause for this has not been discovered. There was no indication of fungous growth or change of any kind, and the total strength was not affected.

The system of cutting up the planks differed somewhat from that used for longleaf pine, but the specimens were cut so as to come from the same strip or from corresponding strips with reference to the grain. Each specimen received a reference number locating its position in the original plank.

All specimens for one series were cut from the same plank, and in such a manner as to have, as nearly as possible, the same grain, diagonal for the beams.

The beams were all cut 40 inches in length. The five compression series of 1903 were treated in 12-inch lengths, and the eleven series of 1904 in 8-inch lengths. The shearing series were treated in 6-inch lengths.

All of the end compression specimens were cut to 5¾-inch lengths for testing, except sets Nos. 101, 102, 103, 104, 106, 107, 109, of series of 1903, which were cut to 6-inch lengths. The reason for this change has already been explained on page 35.

In numbering the specimens for the tests, numbers less than 100 were used for beams, the unit signifying the moisture condition of the set, and the tens the series. End compression specimens were numbered over 100, shearing over 200, and compression at right angles to grain over 300. All numbers ending in 1 were soaked, and those ending in 2 green, and so on. Thus, 132 designated compression parallel to grain (100), moisture condition green (2), and fourth series (30), the first series being 0. In this way it was possible to keep track of all the numerous specimens during their various treatments, and the disks cut from each, without confusion.

There were for the spruce in all 12 beam series (5 sets direct and 2 resoaked), 16 end compression (8 sets direct and 4 reabsorbed), 16 shearing (7 sets direct and 3 reabsorbed), and 5 compression at right angles to grain.

The detailed treatment which each set received is given in the table of individual tests.

CHESTNUT.

The chestnut lumber was purchased in the local market and brought as 2½-inch plank directly from a sawmill in this region, where it was sawed from the logs at the time, and therefore in a perfectly green condition. In fact, several of the specimens sank when placed in water. The specimens were prepared and numbered in the same manner as the spruce specimens and were of the same size. All pieces of the same series were cut from the same log, but occasionally from several planks. Careful attention was paid to the grain, in order to have it as nearly uniform as possible. In selecting the specimens it was preferred to take a series as far as possible from the same section of the log, rather than from the same strip extending through several sections.

There were 10 series of bending, 10 of end compression, and 10 of shearing tests, half radial and half tangential.

Much difficulty was experienced in drying out the chestnut, as the outer portion would dry rapidly, leaving the center actually wet, and containing free water which evaporated very slowly. This effect of "casehardening" is indicated in Pl. IV, fig. 2, which shows one of the beams sectioned at short intervals. The black central spot is the wet portion. Even with the most careful drying in steam the central part would often contain as much as 75 per cent moisture, while the outside was reduced to 12 per cent. The impracticability of making any tests between the green condition of about 116 per cent and that of 12 per cent is evident. Nevertheless, an attempt was made to obtain an intermediate degree for the beam sets Nos. 3 and 6 and shearing set No. 203 by removing them from the kiln just before the damp spot had disappeared, and placing them in the damp box for over a month (see fig. 20).

The kiln-drying was begun at a temperature of about 110° F. and humidity of 60 per cent for two days, and then 130° to 140° and 75 per cent humidity (with condensed steam) for nearly a month, at which point the 12 per cent pieces were removed and tested and the rest kept at a dry heat of about 130° for a week longer.

The detailed treatment for each "set" is given in the tables of individual tests.

THE RESULTS.

THE FIBER-SATURATION POINT.

Under the topic of "Reabsorption of moisture," page 18, was brought out the fact that the water in wood may exist in two conditions—as free water, contained in the pores of the wood, like honey in a honeycomb, and as moisture absorbed within the substance of the cell walls. In wet and green woods the water exists in both conditions, the free water evidently having no particular effect upon the strength, and merely adding to the weight of the block. In determining the moisture degree both the free water and the absorbed are necessarily included, since there is no means of distinguishing between the two. Consequently in drying out a piece of wet wood, since the free water must evidently evaporate before the absorbed moisture in the cell walls can begin to dry out, there will be a period during which the strength remains constant although varying degrees of moisture are indicated. But just as soon as the free water has disappeared and the cell walls begin to dry the strength will begin to increase. This point I designate the *fiber-saturation point.*

Referring now to the moisture-strength diagrams, this fiber-saturation point will be easily recognized as the point where the steep curved portion is intersected by a horizontal line. This horizontal

line, then, merely shows the excess of moisture in the wood above the amount required to saturate the cell walls, and existing as free water in the pores.

This subject may be approached in the other direction. When a piece of dry wood is immersed in water the water is gradually drawn into the pores and also absorbed by the cell walls of wood substance. As the latter absorbs more and more water the strength decreases until finally a point is reached where the walls are saturated and will hold no more. The strength then ceases to diminish, although the block of wood may still continue to take up water, but only as free water in the pores. This is the fiber-saturation point, and it is evidently the same point at which swelling ceases.

If the moisture in the specimens be unevenly distributed, or if drying be more rapid in one place than in another, the fiber-saturation point is obscured. Suppose a wet specimen be dried in such a manner that the outer surface is drier than this point, while the central portion still contains free water. The result will show an increase in strength although the moisture determination will indicate a degree of moisture beyond the saturation point. Consequently, in the diagram, the result of such a test will be a point above the horizontal line; and a series of such tests will give an uninterrupted curve from the driest to the wettest condition, entirely obscuring the fiber-saturation point, and having all its strength values too high for the indicated moisture degree. This is clearly shown in the results of a number of tests purposely "casehardened," given in figs. 19 and 20, page 118. The correct diagrams are the lower lines, and the rounding-off effect obtained from unevenly dried specimens is shown in the upper curves.

Apparently this fiber-saturation point has heretofore been overlooked, former experimenters making the mistake of rounding off the curve and making the strength values too high. (See figs. 17 and 18.)

A series of special tests was made in order to determine the fiber-saturation point for the three species, which is described in the Appendix on page 114. The results gave the following average values, although it seems probable that considerable variation may occur, due to extrinsic conditions as well as inherent differences in the specimens, and the regular tests do not all agree in this respect:

Longleaf pine	25 per cent of moisture.
Spruce	31 per cent of moisture.
Chestnut	25 per cent of moisture.
Loblolly pine .... heartwood, 22.5; sapwood,	24 per cent of moisture.
Red gum	25 per cent of moisture.
Red fir	23 per cent of moisture.

Evidently, therefore, the curved part of the diagram is the true moisture-strength curve, the horizontal wet line merely indicating free water. But why should this curve stop abruptly at the fiber-saturation point? It would appear theoretically that it should extend on below this point, which fact leads naturally to the question whether there is not some way in which this can actually be accomplished by physical means. Experiment shows that the position of this point upon the curve is a variable quantity and is influenced by extrinsic conditions. Thus, heating the water in which the piece is immersed greatly lowers the fiber-saturation point and consequently lowers the horizontal wet line. In like manner cooling has the opposite effect upon this condition of the fiber.

The subject has not been sufficiently investigated as yet by the author to draw any more definite conclusion as to the behavior of wood in the fiber-saturation condition. That is, heat increases the capacity of the fibers to absorb water and cold decreases it.

EFFECT OF HEAT AND COLD.

A number of tests were made upon heating and boiling the wood and upon frozen wood at low temperature, as explained in Study 6, page 121, Appendix, and the results, which are very marked, are given in Tables 40 and 41.

EFFECT OF PROLONGED SOAKING.

Another study was made to determine what effect prolonged soaking had upon the strength. From the foregoing discussion concerning free water in the pores it would seem that soaking in water at uniform temperature would have no influence upon the strength, or at most that it might possibly decrease it slightly by the walls becoming supersaturated after prolonged soaking. Strange to say, for some unknown reason the reverse appears to be true, and the strength apparently increases very slightly. This conclusion was also reached in some recent German experiments,[a] but it must not be considered conclusive. (See Study 4, page 119, in Appendix, describing the special tests.)

The following conclusions, however, may be relied upon as well established:

Prolonged soaking in cold water does not diminish the strength of wood, which remains that of the green condition unless previously dried and weakened in the drying process.

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[a] Herr Janka in Baumaterialienkunde, Stuttgart, August, 1904.

REABSORPTION AFTER DRYING.

The effect of kiln drying wood and then bringing it back to its original moisture condition by reabsorption and resoaking was mentioned on page 14. As was then explained, those specimens which are to be thoroughly resoaked may be compared directly with the green strength, as represented by the horizontal "wet" line in the diagrams, but those which are to be compared at an intermediate moisture condition must be allowed to absorb moisture from the air and not come in contact with water, for it is possible that water entering the pores might exist as free water even before the walls have had time to become saturated, and might thus give too great a moisture indication. On the longleaf pine compression curve, fig. 8, there is one reabsorption point which falls above the drying curve, probably due to this condition, since those tests were made before the formulation of the fiber-saturation theory and the pieces were allowed to reabsorb by immersion in water for a time.

With the exception just referred to, specimens which have been kiln-dried invariably show a loss in strength when brought back to the wet condition. A special study of the effect of drying was also made, described on page 114, Appendix, and the results are given in Table 34. Evidently this loss is due to the process of drying and not to the soaking, inasmuch as soaking green wood any length of time does not decrease its strength. Nor is the decrease in strength due to loss of volatile oils, since the spruce and chestnut show as great a loss as the longleaf pine. The cause of this deleterious effect of drying is at present unknown, but it appears quite certain that the temperature has much to do with the result produced. The effect of steaming in a closed cylinder shows that the loss in strength is proportional to the steam pressure. (See note on p. 116 of Appendix.)

The averaged results of each set of these reabsorption tests are indicated in figs. 8 and 9 by small detached circles. The results for the spruce end compression tests are averaged in two classes, namely, the 5 series of 1903 and the 11 series of 1904, since the moisture degree was different in the two cases.

The average loss in strength appears to be about the same for the three species and ranges from about 15 to 18 per cent of the original strength, the temperature of drying having been about 130° to 140° F., while steaming four hours at 20 pounds reduces it about 20 per cent.

SPECIFIC GRAVITY IN RELATION TO STRENGTH AND MOISTURE.

The specific gravity of wood is least in its perfectly dry condition, and were no swelling to take place it would increase in the selfsame piece of wood directly with the amount of moisture absorbed and consequently might be used in place of moisture per cent for the abscissæ in the moisture curves. However, since the wood swells until the fiber-saturation point is reached, the specific gravity increases less rapidly than the moisture until this point is passed. In order, therefore, to compare the specific gravity of two pieces of wood, it is manifestly necessary that they be at the same degree of moisture, preferably in the driest condition.

The following table shows how much greater is the ratio of increase in moisture (or weight) than the increase in swelling from the dry to the green condition. In column S is given the increase in volume expressed in per cent of the volume when dry, and in column P the increase in weight of moisture in per cent of the dry weight. The beams are tabulated separately, as they were not oven-dried, and their respective ratios are based on the kiln-dry condition. Were the values for S and P equal, respectively, no change in specific gravity would occur; and were S equal to zero, i. e., no swelling to take place, G would vary with P.[a]

[a] Let G_1=specific gravity of dry wood (at any given condition).

G =specific gravity of green wood (at any other given condition).

m =increase in weight (=moisture absorbed) from the former to the latter condition.

n =corresponding increase in volume.

W_1=weight in the given dry condition.

V_1=volume in the same condition.

C =a constant.

Then—

$P=\frac{m}{W_1}\times 100$=per cent of increase in weight (or moisture) from the former given condition to the latter, based on the former.

$S=\frac{n}{V_1}\times 100$=per cent of increase in volume from the former given condition to the latter, based on the former.

$$G=\frac{W_1+m}{V_1+n}\times C=\frac{W_1\left(1+\frac{m}{W_1}\right)}{V_1\left(1+\frac{n}{V_1}\right)}\times C=G_1\frac{(100+P)}{(100+S)}.$$

TABLE 14.—*Relation of (conditional) specific gravity to swelling and moisture.*

BETWEEN THE OVEN-DRY AND THE GREEN CONDITION.

Species.	Kind of test.	No. of tests.	S, increase in volume in per cent of dry volume.	P, increase in moisture in per cent of dry weight.	G_1, specific gravity of dry wood.	G, specific gravity of green wood.	G, specific gravity of green wood by formula $G=G_1\frac{(100+P)}{(100+S)}$.
Longleaf pine	Compression parallel to grain.	12	10.8	18.4	0.62	0.67	0.665
Spruce	do	42	11.4	27.5	.42	.47	.48
	Shearing	24	12.2	21.8	.43	.49	.47
	Compression at right angles to grain.	15	9.0	22.9	.42	.47	.47
Average for spruce		81	11.1	24.9	.42	.476	.477
Chestnut	Compression parallel to grain.	20	9.3	123.0	.47	.97	.96
	Shearing	20	10.6	123.0	.46	.90	.93
Average for chestnut		40	10.0	123.0	.465	.935	.945

BETWEEN THE KILN-DRY AND THE GREEN CONDITION.

Longleaf pine	Bending	10	9.0	15.8	0.66	0.72	0.70
Spruce	do	28	8.3	24.1	.40	.49	.46
Chestnut	do	22	9.9	109.0	.49	.95	.93

This may be summed up in a general statement that the amount of swelling from the very dry to the green or water-soaked condition is nearly the same for the three species, being 10 to 11 per cent of the dry volume. The corresponding increase in moisture is very much greater than this, varying widely in the three species, so that the specific gravity is increased, though not in as great a ratio as is the weight.

On the other hand, differences in the specific gravity of different pieces of wood at the same moisture degree, or the *inherent* specific gravity, as it may be termed in contradistinction to the *conditional* specific gravity, or specific gravity affected by moisture, as described above, bears a totally different relation to the strength. The strength increases with the inherent specific gravity, whereas it decreases with the conditional specific gravity. This condition must be clearly understood, and if the specific gravities be always taken in the dry condition of the wood no confusion will arise, since both kinds are identical when there is no moisture present in the wood. Whether the wood is absolutely dry or only thoroughly oven-dry or kiln-dry makes little practical difference, since the conditional specific gravity is nearly constant at this degree of dryness.

It is not within the scope of this investigation to determine the relation of inherent specific gravity to strength. However, there

was enough variation in longleaf pine compression tests to indicate this relation, and it has been worked out in combination with the moisture effect, and the series of curves developed as explained on page 72. The result is shown in fig. 7, where each curve represents the moisture strength relation for a different dry weight or inherent specific gravity. These curves were derived from six series, a seventh which was unusually resinous being discarded.

The results may be closely expressed in an equation, which is as follows:

$$C = G\ (22.1p^2 - 1335p + 25610).$$

Where C = crushing strength in pounds per square inch.
G = specific gravity of dry wood.
p = per cent of moisture, based on disk method.

Thus, for example, what is the crushing strength of a piece of longleaf pine at 10 per cent of moisture, its dry specific gravity being 0.62?

$C = 0.62\ (2210 - 13350 + 25610) = 8{,}971.4$ pounds per square inch, which will be found to correspond to the curve in fig. 7.

The maximum variation from this equation of a single test was 17 per cent above and 22 per cent below; of a single series, 9 per cent above and 22 per cent below.

A more thorough study of the relation of inherent specific gravity to the strength of wood than has heretofore been made appears to be highly desirable. There is a remarkable disagreement between various authors in this respect. Janka, from recent tests at Mariabrunn, Germany, finds that the strength increases more rapidly than the specific gravity (as a function of the second degree); Bauschinger concludes that the strength varies directly with the specific gravity, and certain former tests of the Division of Forestry indicate that it increases at a much less ratio than the specific gravity.[a]

Until some more definite knowledge is had concerning this subject it will probably be best to assume that the strength varies directly as the specific gravity, and in applying the results of our tests to wood of other densities this assumption may be made.

OTHER RESULTS AND COMPARISONS WITH TABLES.

A comparison of the curves shows the longleaf pine to be the steepest, the spruce next, and the chestnut the least steep. If, however, the relative dry weights be taken into consideration, the strength being considered proportional to the weights, it will be found that in the dry condition, weight for weight, spruce is the strongest and longleaf pine the weakest of the three species. In the green

[a] Baumaterialienkunde, Stuttgart, August, 1904; Bauschinger, Munich, Germany, 1887; Bulletin No. 8, Division of Forestry, Plate XI.

condition, however, the reverse is the case. Weight for weight, moreover, kiln-dry spruce is actually as strong and stiff in compression and bending as steel of fair quality, and considerably stronger than cast iron.

Although the curves showing the relation between compression strength and moisture for the three species differ in steepness, it is a curious fact that, if the vertical ordinate of strength be expressed relatively between the two extremes of moisture instead of in absolute terms and the two extreme points on the curves be made to coincide, the curves for the three species very nearly coincide, showing that the rate of variation in strength between the extreme condition with regard to moisture is the same for all three species.

By an examination of the tables it will be observed that the greatest increase due to drying is with the end compression tests, ultimate crushing strength, and strength at elastic limit; the modulus of rupture and stress at elastic limit for beams comes next, and the modulus of elasticity comes last. These ratios from the wet to the kiln-dry condition (3½ per cent) are given below:

TABLE 15.—*Ratio of strengths from wet to kiln-dry condition.*

Kind of strength.	Longleaf pine.	Spruce.	Chestnut.
C	2.89	3.71	2.83
F	2.60	3.80	2.40
R	2.50	2.81	2.09
f	2.90	2.90	2.30
Xr (3 per cent deformation)	....	2.58	....
St and *Sr* (variable)	2.01	2.03	1.55
Ec	1.63	2.26	1.43
E	1.59	1.43	1.44

If these ratios be multiplied by the shrinkage factors explained on page 78, so that they represent the relative strength of the selfsame block of wood instead of unit values, they become:

TABLE 16.—*Ratio of strengths from wet to kiln-dry condition, corrected for shrinkage.*

Kind of strength.	Longleaf pine.		Spruce.		Chestnut.	
	Ratio.	Factor.	Ratio.	Factor.	Ratio.	Factor.
C	2.60	0.90	3.41	0.92	2.55	0.90
F	2.34	.90	3.49	.92	2.26	.90
R	2.20	.88	2.50	.89	1.82	.87
f	2.55	.88	2.58	.89	2.00	.87
Xr	....	....	[a]2.48	[a].96	....	....
St and *Sr*	1.91	[a].95	1.95	[a].96	1.47	[a].95
Ec	1.47	.90	2.08	.92	1.29	.90
E	1.35	.85	1.23	.86	1.21	.84

[a] Since no notable shrinkage occurs along the grain, these factors are for shrinkage in width only.

Theoretically, the extreme fiber stress at the elastic limit in bending should very nearly equal the ultimate strength in compression parallel to grain, as has been explained by Mr. S. T. Neely in Circular 18 of the Forest Service. Our curves confirm this theory, as will be

seen by reference to the comparison of values for spruce given in fig. 16. A more striking evidence of this is shown in fig. 13, in which the dotted curve for the compression values is derived from specimens cut from the beams whose curve of fiber stress at elastic limit is given. As these tests were made from identically the same material, and at practically the same time, the results are strictly comparable. The average results of the seven longleaf pine beam series as they stand, without harmonizing by curves, are set forth in Table 5, and four series of the spruce beams in Table 6. The results are more concisely given in Table 17:

TABLE 17.—*The relation of stress at elastic limit in bending to the crushing strength of blocks cut therefrom in pounds per square inch.*

LONGLEAF PINE.

Moisture condition.	Soaked 50 per cent.	Green 23 per cent.	14 per cent.	11.5 per cent.	9.5 per cent.	Kiln-dry 6.2 per cent.	Reabsorbed 34 per cent.
Number of tests averaged	5	5	5	5	4	5	5
f in bending	4,920	5,944	6,924	7,852	9,280	11,550	4,645
C in compression	4,668	5,100	6,466	7,466	8,985	10,910	4,218
Per cent *f* is in excess of *C*	5.5	16.5	7.1	5.2	3.3	5.9	10.1

SPRUCE.

Moisture condition.	Soaked 30 per cent.	Green 30 per cent.	10 per cent.	8.1 per cent.	Kiln-dry 3.9 per cent.	Reabsorbed 60 per cent.
Number of tests averaged	5	4	5	3	4	1
f in bending	3,002	3,362	6,458	8,400	10,170	3,880
C in compression	2,680	3,025	6,120	7,610	9,335	2,520
Per cent *f* is in excess of *C*	12.0	11.1	5.5	10.4	9.0	54

CHESTNUT (ONE TEST OF EACH).

Moisture condition.	Soaked 130 per cent.	Green 113 per cent.	24 per cent.	23.3 per cent.	20.8 per cent.	Kiln-dry 6.6 per cent.	Reabsorbed 60 per cent.
f in bending	4,050	3,370	2,960	2,710	5,050	6,010	3,320
C in compression	3,380	2,860	2,180	2,440	4,080	6,780	2,090
Per cent *f* is in excess of *C*	19.8	17.8	35.8	11.0	23.8	11.3	59.0

In regard to the shearing tests there is little to be said more than to review what has already been stated on page 52. The results show much irregularity and great uncertainty. While careful drying, as a rule, increases the strength, in some cases the strength appears to fall off again as the piece becomes very dry. Radial shear in longleaf pine is stronger than tangential,[a] provided the piece is perfect and has not been injured in drying; but, on the other hand, it is of more uncertain result on account of the ease with which it checks. In the spruce and chestnut, the difference between the two

[a] In the case of woods with large medullary rays, such as oak, the reverse is true, namely, tangential shearing strength is considerably stronger than radial.

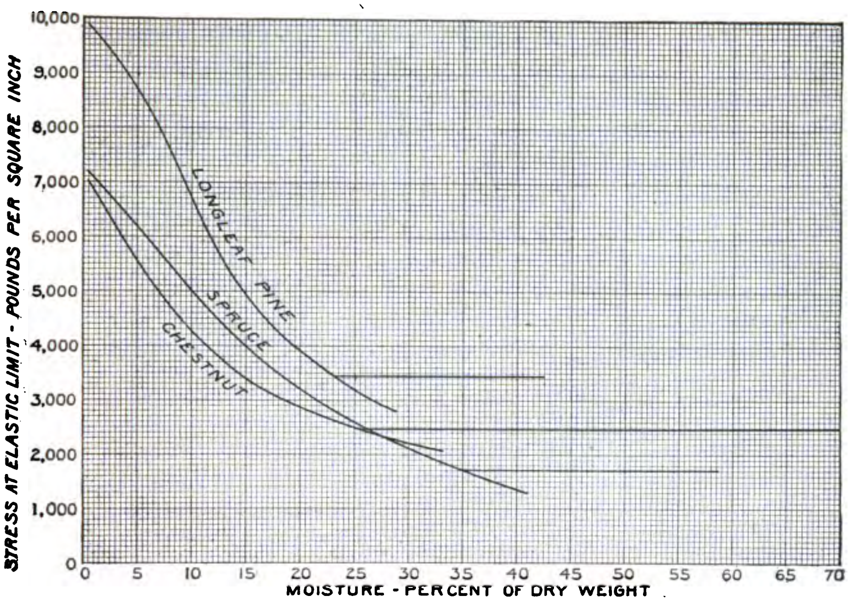

FIG. 12.—Variation of stress at elastic limit with moisture in compression parallel to grain.

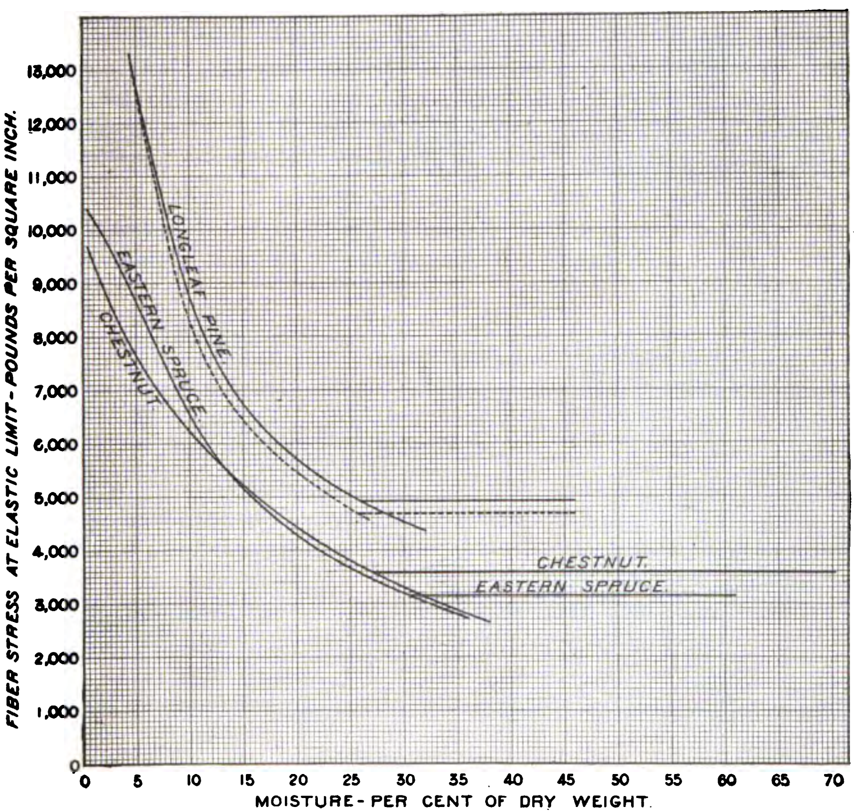

FIG. 13.—Variation of stress at elastic limit with moisture in bending.

kinds of shear is not sufficiently marked to justify distinguishing between them. For these various reasons, no distinction has been made between radial and tangential shear in obtaining the average curves. It is perhaps unsafe to count upon very much increase in the shearing strength above that of the green or wet condition.

In regard to the volatile oil and resin contained, the former, as was shown on page 68, is ordinarily so small in amount that it may be disregarded, especially since but little of it is evaporated, even in drying the disks at 208° F. The resin, however, evidently tends to increase the strength in the dry condition. The longleaf pine series, which contained an abnormal amount of resin, showed both in the beam and in the compression tests a striking dissimilarity to the other series in the character of their moisture curves, the curves of the resinous pieces being very much the steeper. Further tests, however, will be necessary before any exact conclusion as to the influence of the resin can be drawn. If it appears advantageous to the strength to have an excess of resin in the wood, it appears also, that the apparent gain is overbalanced by the consequent increase in the weight.[a]

In the foregoing pages the endeavor has been to cover all the factors of conditions and tests which might in any way influence the results we have been seeking, and to explain fully their bearing upon the subject. It is believed that the fullness of details has been justified for the sake of arriving at the fundamental properties of wood and of presenting the results in an unprejudiced view, and in such a manner that any question regarding the results might be answered from the context. There is one more consideration, however, of some importance, which is yet to be discussed, namely, the speed of testing.

The greater the speed of deflection the higher is the indicated load. A series of tests has been undertaken in order to establish the exact relation of testing speed to strength. Before two tests can be compared not only must the moisture conditions be taken into consideration, but also the rate of application of the load. The three principal ways in which a specimen may be stressed were described on page 20. In this investigation the corresponding tests have all been made at practically the same speed, and therefore no correction for this factor is necessary.

In applying these average results to other material, it must be borne in mind that individual specimens are apt to diverge more or less, so that the given factors do not necessarily apply to single pieces. The factors should not, therefore, be used too strictly for individual pieces.

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[a] It may be noted that the resin has a decidedly beneficial effect in reducing the hydroscopic condition of the material, and also as a preservative.

TABLES FROM AVERAGE CURVES.

TABLE 18.—*Compression strength parallel to grain.*

[Results from average curves, figs. 8, 10, and 12.]

Moisture per cent, dry weight.	Crushing strength.			Modulus of elasticity.			Stress at elastic limit.		
	Long-leaf pine.	Spruce.	Chest-nut.	Long-leaf. pine.	Spruce.	Chest-nut.	Long-leaf pine.	Spruce.	Chest-nut.
	Lbs. per sq. inch.	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
1	14,800	9,700	9,500	2,280	1,530	1,215	9,750	7,000	6,800
2	14,050	9,400	9,100	2,160	1,460	1,180	9,550	6,800	6,450
3	13,300	9,000	8,750	2,050	1,400	1,145	9,300	6,600	6,100
4	12,550	8,700	8,350	1,930	1,330	1,115	9,000	6,350	5,800
5	11,850	8,300	8,000	1,830	1,270	1,090	8,700	6,150	5,500
6	11,100	7,900	7,550	1,740	1,210	1,060	8,400	5,900	5,200
7	10,450	7,500	7,150	1,670	1,160	1,040	8,000	5,700	4,900
8	9,850	7,100	6,800	1,605	1,120	1,020	7,600	5,450	4,650
9	9,250	6,750	6,450	1,550	1,080	1,000	7,100	5,200	4,400
10	8,750	6,400	6,100	1,500	1,040	980	6,650	5,000	4,200
11	8,250	6,100	5,800	1,455	1,010	960	6,200	4,750	4,000
12	7,750	5,800	5,550	1,410	980	945	5,800	4,550	3,800
13	7,300	5,500	5,300	1,370	950	930	5,500	4,350	3,600
14	6,850	5,250	5,000	1,330	925	915	5,150	4,150	3,500
15	6,450	5,000	4,800	1,300	900	905	4,900	3,950	3,350
16	6,050	4,750	4,600	1,265	875	890	4,650	3,800	3,200
17	5,650	4,550	4,400	1,235	855	880	4,450	3,650	3,100
17.5 [a]				1,220					
18	5,300	4,350	4,200	1,205	835	865	4,250	3,500	3,000
19	4,950	4,200	4,000	1,180	815	855	4,050	3,300	2,900
20	4,600	4,000	3,850	1,155	795	845	3,900	3,200	2,800
20.3 [a]	4,500								
21	4,250	3,850	3,700	1,130	780	835	3,750	3,050	2,730
22	3,900	3,700	3,500	1,105	765	825	3,600	2,900	2,650
23	(3,650)	3,550	3,400	(1,080)	750	815	3,500	2,800	2,600
23.3 [a]							3,450		
24	(3,350)	3,400	3,230	(1,075)	735	805	3,350	2,700	2,530
25	(3,050)	3,300	3,100	(1,060)	720	800	3,200	2,600	
25. [a]									2,470
25.5 [a]			3,030						
26		3,150	2,980	(1,040)	705	790	3,100	2,450	
26.2 [a]						789			
27		3,050	2,840		690		3,000	2,350	
28		2,950			680			2,250	
29		2,850			670			2,150	
30		2,750			655			2,050	
31		2,650			645			2,000	
32		2,550			635			1,900	
33		2,480			624			1,800	
34					613			1,730	
34. [a]		2,400							
34.5 [a]								1,700	
34.7 [a]					605				
Number of tests	49	128	58	49	128	58	49	128	58
Specific gravity dry wood	0.63	0.41	0.46	0.63	0.41	0.46	0.63	0.41	0.46
PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF ANY SINGLE TEST.									
Above	22	23	19	51	29	26	28	53	30
Below	34	19	19	31	58	37	29	48	36
PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF 80 PER CENT OF THE TESTS.									
Above	10	9	7	16	17	17	21	25	11
Below	18	12	10	21	22	24	22	26	18
Rings per inch	26.4	17.5	5.9	26.4	17.5	5.9	26.4	17.5	5.9

[a] Fiber-saturation point on curve.

TABLE 19.—*Bending strength.*

[Results from average curves, figs. 9, 11, and 13.]

Moisture per cent, dry weight.	Modulus of rupture.			Modulus of elasticity.			Stress at elastic limit.		
	Long-leaf pine.	Spruce.	Chestnut.	Long-leaf pine.	Spruce.	Chestnut.	Long-leaf pine.	Spruce.	Chestnut.
	Lbs. per sq. inch.	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*1,000 lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
1		15,400	13,500		1,870	1,630		10,200	9,350
2	(23,900)	15,050	13,150	(3,010)	1,840	1,585	(15,400)	9,850	8,900
3	(22,600)	14,700	12,800	2,890	1,810	1,545	(14,500)	9,500	8,450
4	21,300	14,300	12,450	2,770	1,780	1,500	13,600	9,100	8,000
5	20,000	13,800	12,100	2,635	1,755	1,465	12,700	8,700	7,700
6	18,700	13,300	11,700	2,505	1,725	1,430	11,800	8,200	7,300
7	17,500	12,700	11,300	2,400	1,700	1,395	10,900	7,750	7,000
8	16,400	12,100	10,950	2,300	1,670	1,365	10,100	7,300	6,700
9	15,500	11,550	10,550	2,205	1,645	1,335	9,400	6,900	6,450
10	14,700	11,000	10,200	2,125	1,620	1,310	8,800	6,550	6,200
11	14,000	10,500	9,850	2,050	1,600	1,285	8,250	6,200	6,000
12	13,300	10,000	9,500	1,990	1,575	1,260	7,750	5,900	5,800
13	12,800	9,600	9,150	1,940	1,555	1,240	7,400	5,650	5,600
14	12,300	9,200	8,850	1,895	1,530	1,220	7,000	5,400	5,400
15	11,800	8,800	8,500	1,860	1,515	1,200	6,700	5,200	5,200
16	11,400	8,450	8,250	1,825	1,490	1,180	6,450	5,000	5,050
17	11,050	8,100	7,950	1,795	1,475	1,160	6,250	4,800	4,900
17.5 [a]				1,783					
18	10,700	7,850	7,700	1,770	1,455	1,145	6,050	4,600	4,700
19	10,400	7,550	7,450	1,745	1,440	1,125	5,850	4,450	4,550
20	10,100	7,250	7,200	1,725	1,425	1,110	5,700	4,300	4,450
21	9,850	7,000	6,950	1,705	1,405	1,095	5,550	4,150	4,300
22	9,600	6,800	6,700	1,690	1,390	1,080	5,400	4,000	4,200
23	9,350	6,550	6,500	(1,670)	1,375	1,065	5,250	3,900	4,050
24	9,150	6,350	6,300	(1,655)	1,360	1,053	5,150	3,800	3,950
24.5 [a]						1,060			
25		6,150	6,100	(1,645)	1,350		5,000	3,680	3,800
25.0 [a]	8,900								
25.2 [a]			6,040						
25.8 [a]							4,920		
26	8,700	5,950	5,900		1,335		4,900	3,580	3,700
27		5,750			1,325			3,480	3,600
27.2 [a]									3,580
28		5,600			1,310			3,380	3,500
29		5,400			1,300			3,300	
30		5,250			1,290			3,200	
30.5 [a]		5,170						3,170	
31					1,280				
32					1,270				
32.8 [a]					1,262				
Numbers of tests	30	67	45	30	65	52	29	65	51
Specific gravity dry wood	0.66	0.42	0.47	0.66	0.42	0.47	0.66	0.42	0.47

PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF ANY SINGLE TEST.

Above	22	18	27	22	36	35	33	32	34
Below	34	35	35	31	22	32	45	27	42

PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF 80 PER CENT OF THE TESTS.

Above	11	12	17	17	14	14	21	16	18
Below	21	7	19	19	12	26	15	14	23
Rings per inch	16.0	17.5	6.7	16.0	17.5	6.7	16.0	17.5	6.7

[a] Fiber-saturation point on curve.

TABLE 20.—*Shearing strength, and compression strength at right angles to grain.*

[Results from average curves, figs. 14 and 15.]

Moisture per cent, dry weight.	Shearing.			Compression. Spruce.	
	Longleaf pine.	Spruce.	Chestnut.	Deformation of 3 per cent.	Deformation of 15 per cent.
	Lbs. per sq. inch.	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
2	2,160	1,360	1,105	1,340	1,640
4	2,130	1,305	1,080	1,220	1,530
6	2,050	1,245	1,050	1,115	1,430
8	1,920	1,180	1,020	1,025	1,330
10	1,760	1,115	985	950	1,250
12	1,600	1,060	950	880	1,170
14	1,460	1,010	915	820	1,095
16	1,340	960	880	770	1,030
18	1,230	920	845	720	965
20	1,150	880	810	680	910
22	1,080	850	780	640	860
23.0 [a]	1,050	....	....	....	....
24	1,020	815	750	605	810
25.5 [a]	....	....	730	....	....
26	980	785	725	570	770
28	....	760	....	540	730
30	....	730	....	510	695
32	....	710	....	485	685
34	....	690	....	....	....
36	....	665	....	....	....
38.0 [a]	....	650	....	....	....
Number of tests	24	110	60	60	....
Specific gravity dry wood	0.66	0.42	0.46	0.42	....
PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF ANY SINGLE TEST.					
Above	....	42	23	23	....
Below	....	43	35	35	....
PER CENT OF MAXIMUM VARIATION FROM AVERAGE OF 80 PER CENT OF THE TESTS.					
Above	....	18	12	12	....
Below	....	23	20	20	....
Rings per inch	19.0	19.0	8.0	18.7	....

a Fiber-saturation point on curve.

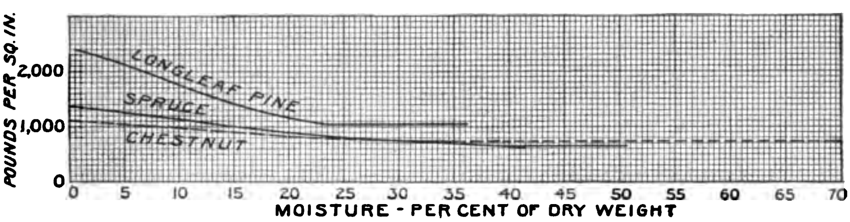

FIG. 14.—Variation of shearing strength with moisture.

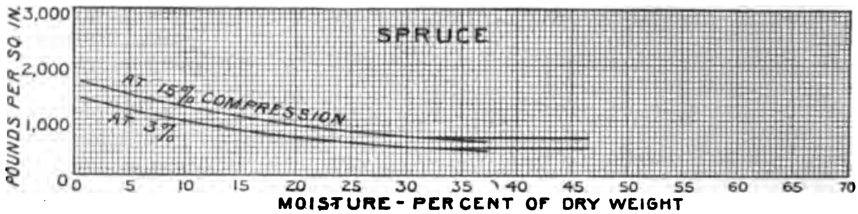

FIG. 15.—Variation of strength with moisture in compression at right angles to grain. Spruce.

TABLE 21.—*Variation with moisture and dry specific gravity of compression strength parallel to grain. Longleaf pine.*

[Results from average curves, fig. 7.]

This table is derived graphically by the method explained on page 72.
It is based upon 49 tests, and applies to heartwood free from imperfections having 20 to 30 rings per inch and a normal amount of resin—that is, less than 1 per cent of volatile oil.

Moisture per cent.	Dry specific gravity.							
	.85	.79	.74	.68	.62	.57	.51	.45
	Pounds per square inch.							
0	11,500	12,900	14,400	15,900	17,500	18,900	20,300	21,700
2	10,300	11,600	12,900	14,200	15,600	16,900	18,200	19,600
4	9,200	10,400	11,600	12,800	13,900	15,100	16,200	17,500
6	8,200	9,200	10,300	11,400	12,400	13,500	14,500	15,500
8	7,300	8,200	9,200	10,100	11,000	12,000	12,900	13,800
10	6,500	7,300	8,100	9,000	9,800	10,600	11,400	12,200
12	5,700	6,500	7,200	7,900	8,700	9,400	10,100	10,800
14	5,100	5,700	6,400	7,000	7,700	8,300	8,900	9,500
16	4,500	5,100	5,600	6,200	6,800	7,300	7,900	8,400
18	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500
20	3,500	3,900	4,400	4,800	5,300	5,700	6,100	6,500
20.4 [a]	3,400	3,800	4,300	4,700	5,100	5,600	6,000	6,400
22	3,100	3,500	3,900	4,300	4,600	5,000	5,400	5,800
24	2,700	3,000	3,400	3,800	4,100	4,400	4,800	5,100

[a] Average green condition.

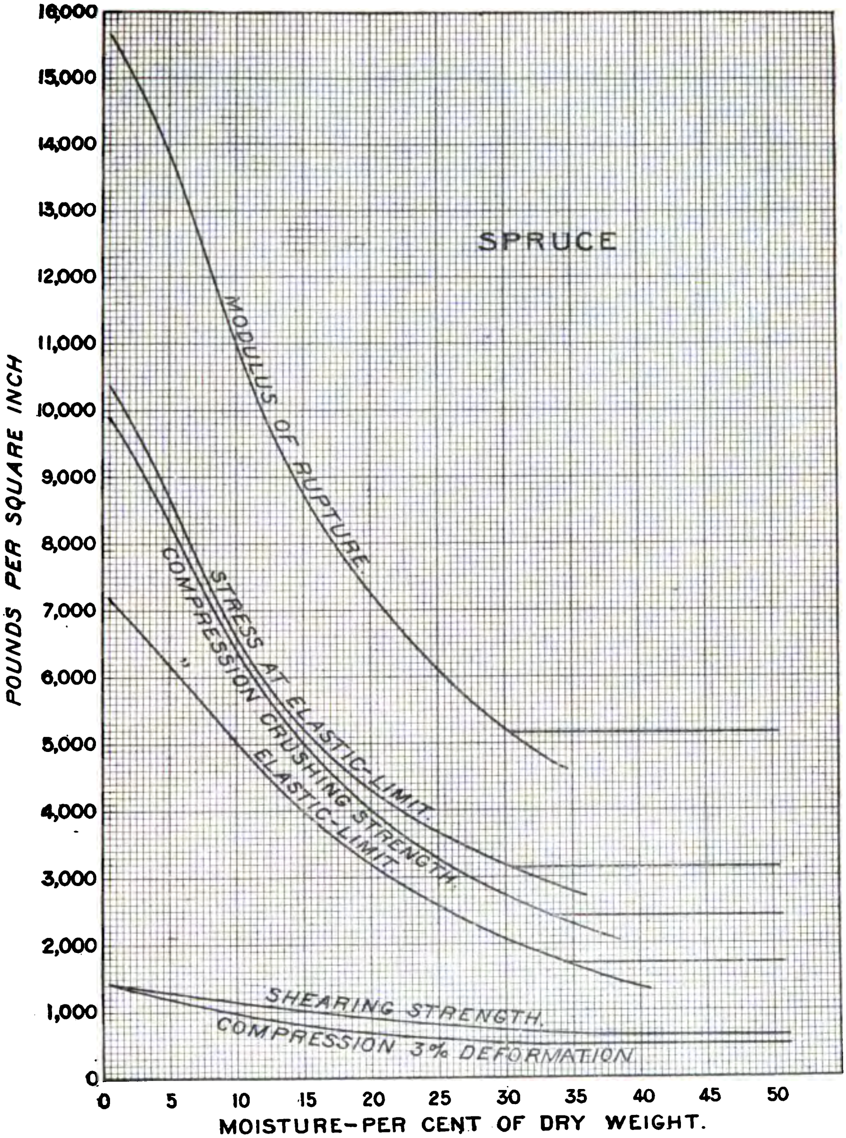

FIG. 16.—Comparison of the various strength values of spruce with variation in moisture.
(The two upper curves are from bending tests and the lowest one from compression at right angles to grain.)

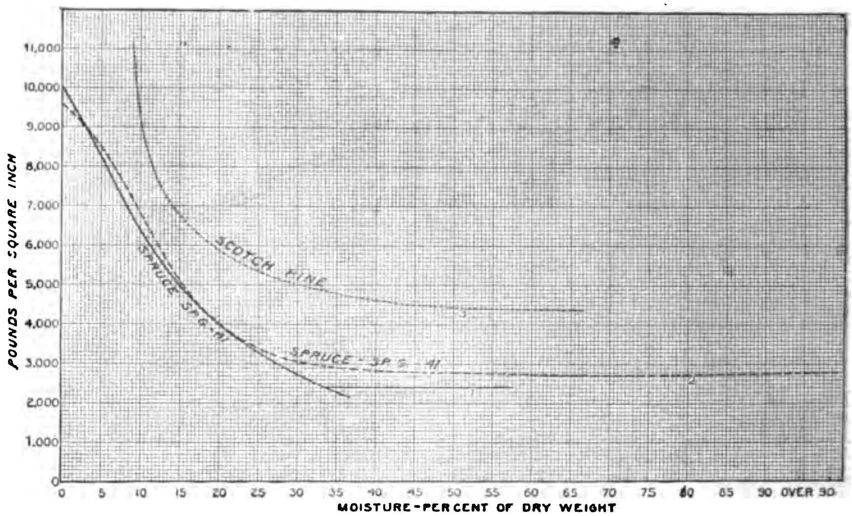

FIG. 17.—Comparison of moisture-strength curves obtained by the Forest Service and in European investigations. Compression parallel to grain:

1. Spruce, specific gravity, 0.41. By the Forest Service, 1905.
2. Spruce, specific gravity, 0.41. By G. Janka, Mariabrunn, Germany, 1904.
3. Scotch pine. By Bauschinger, Munich, Germany, 1887.

MOISTURE-STRENGTH REDUCTION TABLES.

The reduction tables, Nos. 22 to 33, have been compiled from the curves in order to give in convenient form a means of readily reducing the strength of a piece of wood at a known moisture degree to the corresponding value at any other degree.

Thus: Suppose the crushing strength of a given piece of spruce has been obtained at 12 per cent of moisture, and the strength is required at 20 per cent. In the spruce reduction table No. 23 will be found, in the top row, 12 per cent. Looking down this column until opposite the figure 20 in the left-hand column, the factor 0.69 is found. This is the factor by which the given strength at 12 per cent moisture should be multiplied to reduce it to the equivalent at 20 per cent moisture.

Factors, derived from the average curves, by which the strength values of wood, at any given per cent of moisture content may be multiplied to obtain the equivalent values at any other per cent of moisture. The headings of the rows and columns in the tables are per cents of moisture based on the dry weight.

TABLE 22.—*Reduction factors for crushing strength of longleaf pine.*

[Compression parallel to grain.]

TO— Moisture per cent.	FROM— Moisture per cent.											
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	20.3 [a]	22.
2	1	1.120	1.265	1.425	1.605	1.81	2.05	2.32	2.65	3.05	3.12	3.60
4	.894	1	1.13	1.275	1.435	1.62	1.83	2.07	2.37	2.73	2.79	3.22
6	.790	.885	1	1.125	1.27	1.43	1.62	1.835	2.09	2.45	2.47	2.84
8	.702	.785	.888	1	1.125	1.27	1.44	1.63	1.86	2.14	2.19	2.53
10	.623	.698	.788	.887	1	1.13	1.28	1.445	1.65	1.90	1.945	2.24
12	.552	.618	.699	.786	.885	1	1.13	1.28	1.46	1.685	1.725	1.99
14	.488	.546	.617	.695	.783	.884	1	1.13	1.29	1.49	1.52	1.755
16	.431	.482	.545	.614	.691	.781	.884	1	1.14	1.315	1.345	1.55
18	.377	.422	.478	.538	.605	.684	.774	.876	1	1.15	1.18	1.36
20	.328	.367	.414	.467	.526	.593	.672	.760	.867	1	1.02	1.18
20.3 [a]	.320	.359	.406	.457	.514	.581	.657	.744	.849	.978	1	1.155
22	.278	.311	.351	.396	.445	.503	.569	.645	.735	.848	.866	1

[a] Green.

TABLE 23.—*Reduction factors for crushing strength of red spruce.*

[Compression parallel to grain.]

TO— Moisture per cent.	FROM— Moisture per cent.																
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.[a]
2	1	1.08	1.19	1.325	1.47	1.62	1.79	1.98	2.16	2.35	2.54	2.77	2.98	3.19	3.42	3.69	3.92
4	.926	1	1.10	1.225	1.36	1.50	1.66	1.83	2.00	2.18	2.35	2.56	2.76	2.95	3.17	3.41	3.63
6	.841	.908	1	1.11	1.235	1.36	1.505	1.665	1.82	1.98	2.14	2.33	2.51	2.68	2.88	3.10	3.29
8	.756	.816	.899	1	1.11	1.225	1.35	1.495	1.63	1.78	1.92	2.09	2.25	2.41	2.58	2.79	2.96
10	.681	.736	.810	.902	1	1.105	1.22	1.35	1.47	1.60	1.73	1.885	2.03	2.17	2.33	2.51	2.67
12	.617	.667	.734	.817	.907	1	1.105	1.22	1.335	1.45	1.57	1.705	1.84	1.97	2.11	2.37	2.42
14	.554	.598	.658	.732	.813	.896	1	1.105	1.21	1.315	1.42	1.545	1.665	1.78	1.91	2.06	2.19
16	.505	.546	.601	.669	.742	.820	.914	1	1.09	1.19	1.285	1.40	1.51	1.61	1.73	1.86	1.98
18	.463	.500	.550	.613	.680	.750	.836	.915	1	1.09	1.175	1.28	1.38	1.475	1.58	1.705	1.815
20	.426	.460	.506	.564	.625	.690	.769	.842	.920	1	1.08	1.18	1.27	1.355	1.455	1.57	1.67
22	.394	.425	.468	.521	.578	.638	.711	.778	.851	.925	1	1.09	1.175	1.255	1.345	1.45	1.54
24	.362	.391	.430	.479	.531	.586	.654	.715	.782	.850	.919	1	1.08	1.15	1.235	1.335	1.42
26	.335	.362	.399	.443	.492	.543	.606	.663	.724	.787	.851	.926	1	1.07	1.15	1.235	1.31
28	.314	.339	.373	.415	.461	.508	.567	.621	.678	.737	.797	.867	.936	1	1.07	1.155	1.23
30	.292	.316	.348	.387	.430	.474	.528	.579	.632	.690	.743	.808	.873	.932	1	1.08	1.145
32	.271	.293	.323	.359	.398	.440	.490	.536	.586	.637	.689	.750	.810	.865	.928	1	1.06
34[a]	.255	.276	.304	.338	.375	.414	.461	.505	.551	.600	.649	.706	.762	.814	.874	.941	1

[a] Green.

TABLE 24.—*Reduction factors for crushing strength of chestnut.*

[Compression parallel to grain.]

TO— Moisture per cent.	FROM— Moisture per cent. 2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.5.[a]	26.
2	1	1.09	1.205	1.34	1.49	1.64	1.82	1.98	2.17	2.36	2.60	2.82	3.00	3.05
4	.917	1	1.105	1.23	1.37	1.505	1.67	1.815	1.99	2.17	2.39	2.59	2.76	2.80
6	.830	.904	1	1.11	1.24	1.36	1.51	1.64	1.80	1.96	2.16	2.34	2.49	2.53
8	.747	.814	.901	1	1.115	1.225	1.36	1.48	1.62	1.765	1.945	2.11	2.25	2.28
10	.670	.730	.808	.896	1	1.10	1.22	1.325	1.45	1.585	1.74	1.89	2.01	2.05
12	.610	.664	.735	.816	.910	1	1.11	1.205	1.32	1.44	1.585	1.72	1.835	1.865
14	.549	.598	.662	.735	.820	.901	1	1.085	1.19	1.30	1.43	1.55	1.65	1.68
16	.505	.551	.609	.677	.754	.829	.920	1	1.09	1.195	1.315	1.425	1.52	1.545
18	.461	.503	.556	.617	.688	.757	.840	.914	1	1.09	1.20	1.30	1.385	1.41
20	.423	.461	.510	.566	.631	.694	.770	.837	.916	1	1.10	1.19	1.27	1.29
22	.384	.419	.464	.515	.574	.631	.700	.761	.834	.909	1	1.085	1.155	1.175
24	.355	.387	.428	.475	.530	.582	.646	.702	.770	.839	.923	1	1.065	1.085
[a] 25.5	.333	.363	.401	.446	.497	.546	.606	.659	.721	.786	.865	.938	1	1.015
26	.327	.356	.395	.438	.488	.537	.596	.648	.710	.775	.851	.921	.984	1.

[a] Green.

TABLE 25.—*Reduction factors for modulus of rupture of longleaf pine.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.[a]	26.
4	1	1.14	1.30	1.45	1.60	1.73	1.87	1.99	2.11	2.22	2.33	2.39	2.45
6	.877	1	1.14	1.27	1.41	1.52	1.64	1.75	1.855	1.945	2.04	2.10	2.15
8	.770	.877	1	1.115	1.235	1.335	1.44	1.535	1.625	1.71	1.79	1.845	1.885
10	.690	.786	.896	1	1.105	1.195	1.29	1.375	1.455	1.53	1.605	1.65	1.69
12	.624	.711	.811	.904	1	1.08	1.165	1.24	1.32	1.385	1.455	1.495	1.53
14	.577	.658	.750	.836	.925	1	1.08	1.15	1.22	1.28	1.345	1.38	1.415
16	.535	.610	.695	.775	.857	.927	1	1.065	1.13	1.185	1.245	1.28	1.31
18	.502	.572	.653	.728	.804	.870	.938	1	1.06	1.115	1.17	1.20	1.23
20	.474	.540	.616	.687	.759	.821	.885	.935	1	1.05	1.105	1.135	1.16
22	.451	.514	.586	.654	.723	.781	.843	.808	.951	1	1.05	1.08	1.105
24	.429	.490	.558	.623	.689	.745	.804	.856	.906	.954	1	1.03	1.05
[a] 25	.418	.476	.543	.606	.670	.725	.782	.832	.882	.927	.973	1	1.025
26	.408	.466	.531	.592	.655	.708	.764	.814	.862	.906	.951	.978	1

[a] Green.

TABLE 26.—*Reduction factors for modulus of rupture of red spruce.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.															
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	31.5.[a]
2	1	1.055	1.13	1.245	1.37	1.505	1.635	1.78	1.915	2.07	2.21	2.37	2.53	2.69	2.87	2.91
4	.950	1	1.075	1.18	1.30	1.43	1.555	1.69	1.82	1.97	2.10	2.25	2.40	2.55	2.72	2.76
6	.884	.930	1	1.10	1.21	1.33	1.445	1.57	1.695	1.835	1.955	2.09	2.25	2.37	2.53	2.57
8	.804	.846	.910	1	1.10	1.21	1.315	1.43	1.54	1.67	1.78	1.905	2.03	2.16	2.30	2.34
10	.731	.769	.826	.909	1	1.10	1.195	1.30	1.40	1.515	1.62	1.73	1.845	1.965	2.09	2.13
12	.665	.700	.753	.827	.910	1	1.085	1.185	1.275	1.38	1.47	1.575	1.68	1.785	1.905	1.935
14	.612	.644	.692	.761	.837	.920	1	1.09	1.17	1.27	1.355	1.45	1.545	1.645	1.755	1.78
16	.562	.591	.636	.699	.769	.845	.918	1	1.08	1.165	1.245	1.33	1.42	1.51	1.61	1.635
18	.522	.544	.591	.649	.714	.785	.853	.930	1	1.085	1.155	1.235	1.32	1.40	1.495	1.52
20	.482	.507	.545	.600	.659	.725	.788	.858	.924	1	1.065	1.14	1.22	1.295	1.38	1.40
22	.451	.476	.511	.562	.618	.680	.739	.805	.866	.938	1	1.07	1.14	1.215	1.295	1.315
24	.422	.444	.478	.525	.577	.635	.690	.752	.809	.876	.934	1	1.065	1.135	1.21	1.23
26	.396	.417	.448	.492	.541	.595	.647	.704	.757	.821	.875	.937	1	1.06	1.135	1.15
28	.372	.392	.421	.463	.509	.560	.608	.663	.713	.772	.824	.882	.941	1	1.065	1.085
30	.349	.367	.395	.434	.477	.525	.571	.621	.668	.725	.772	.826	.882	.938	1	1.015
[a] 31.5	.344	.362	.389	.427	.470	.517	.562	.611	.659	.714	.760	.814	.868	.923	.985	1

[a] Green.

TABLE 27.—*Reduction factors for modulus of rupture of chestnut.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.													
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	25.2.[a]	26.
2	1	1.055	1.125	1.20	1.29	1.385	1.485	1.59	1.71	1.83	1.96	2.09	2.18	2.23
4	.946	1	1.065	1.135	1.22	1.31	1.405	1.51	1.62	1.73	1.86	1.975	2.06	2.11
6	.890	.940	1	1.07	1.145	1.23	1.32	1.42	1.52	1.625	1.745	1.855	1.94	1.98
8	.834	.880	.935	1	1.075	1.15	1.235	1.325	1.42	1.52	1.635	1.74	1.815	1.855
10	.775	.820	.872	.931	1	1.07	1.15	1.235	1.325	1.415	1.52	1.62	1.69	1.73
12	.723	.763	.813	.868	.933	1	1.075	1.15	1.235	1.32	1.42	1.51	1.575	1.61
14	.672	.711	.757	.809	.869	.931	1	1.075	1.15	1.23	1.32	1.405	1.465	1.50
16	.628	.663	.706	.754	.810	.868	.933	1	1.07	1.145	1.23	1.31	1.365	1.40
18	.586	.618	.659	.704	.755	.810	.871	.934	1	1.07	1.15	1.22	1.275	1.305
20	.548	.578	.616	.658	.706	.758	.814	.872	.935	1	1.07	1.145	1.19	1.22
22	.509	.538	.573	.612	.658	.705	.757	.811	.870	.931	1	1.065	1.11	1.135
24	.479	.506	.539	.575	.618	.663	.712	.764	.818	.875	.940	1	1.045	1.07
[a]25.2	.460	.485	.516	.551	.594	.646	.684	.732	.785	.840	.902	.957	1	1.02
26	.448	.474	.505	.534	.579	.620	.667	.715	.766	.820	.880	.936	.977	1

[a] Green.

TABLE 28.—*Reduction factors for modulus of elasticity of longleaf pine.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	17.5. [a]	18.	20.	22.	24.
2	1	1.09	1.20	1.31	1.42	1.51	1.59	1.65	1.69	1.70	1.75	1.78	1.82
4	.92	1	1.11	1.20	1.31	1.39	1.46	1.52	1.55	1.57	1.61	1.63	1.67
6	.831	.903	1	1.09	1.18	1.26	1.32	1.37	1.40	1.41	1.45	1.47	1.57
8	.765	.830	.92	1	1.08	1.16	1.21	1.26	1.29	1.30	1.33	1.36	1.39
10	.705	.766	.848	.922	1	1.06	1.12	1.16	1.19	1.20	1.23	1.25	1.28
12	.661	.720	.796	.865	.938	1	1.05	1.09	1.12	1.13	1.15	1.18	1.20
14	.630	.684	.753	.824	.894	.952	1	1.04	1.06	1.07	1.10	1.12	1.15
16	.607	.659	.730	.794	.860	.917	.964	1	1.02	1.03	1.06	1.08	1.10
[a] 17.5	.592	.645	.714	.776	.842	.897	.944	.977	1	1.01	1.03	1.05	1.08
18	.588	.640	.708	.770	.835	.889	.935	.970	.992	1	1.03	1.05	1.07
20	.573	.623	.690	.750	.813	.866	.910	.946	.966	.975	1	1.02	1.04
22	.564	.612	.678	.737	.799	.851	.895	.928	.950	.957	.983	1	1.02
24	.550	.598	.662	.720	.780	.832	.875	.908	.928	.935	.960	.977	1

[a] Green.

TABLE 29.—*Reduction factors for modulus of elasticity of red spruce.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent. 2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	32.8.[a]
2	1	1.03	1.07	1.10	1.14	1.17	1.20	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.43	1.45	1.46
4	.968	1	1.03	1.07	1.10	1.13	1.16	1.20	1.22	1.25	1.28	1.31	1.33	1.36	1.38	1.40	1.41
6	.938	.969	1	1.05	1.07	1.10	1.13	1.16	1.19	1.21	1.24	1.27	1.29	1.32	1.34	1.36	1.37
8	.908	.938	.969	1	1.05	1.06	1.09	1.12	1.15	1.17	1.20	1.23	1.25	1.28	1.30	1.32	1.35
10	.881	.910	.939	.970	1	1.03	1.06	1.09	1.11	1.14	1.17	1.19	1.21	1.24	1.26	1.27	1.29
12	.856	.884	.913	.944	.972	1	1.05	1.06	1.08	1	1.13	1.16	1.18	1.20	1.22	1.24	1.25
14	.832	.859	.887	.916	.944	.971	1	1.03	1.05	1.07	1.10	1.13	1.15	1.17	1.19	1.20	1.22
16	.810	.832	.864	.892	.919	.946	.974	1	1.02	1.05	1.07	1.10	1.12	1.14	1.16	1.17	1.18
18	.791	.817	.843	.871	.898	.924	.951	.977	1	1.02	1.05	1.07	1.09	1.11	1.13	1.15	1.15
20	.774	.800	.826	.854	.879	.905	.931	.956	.980	1	1.02	1.05	1.07	1.09	1.11	1.12	1.13
22	.756	.781	.806	.833	.858	.882	.909	.934	.956	.975	1	1.02	1.04	1.06	1.08	1.10	1.10
24	.739	.764	.789	.814	.839	.864	.889	.914	.935	.955	.979	1	1.02	1.04	1.06	1.07	1.08
26	.725	.750	.774	.799	.823	.847	.872	.895	.918	.936	.960	.981	1	1.02	1.03	1.05	1.06
28	.712	.736	.759	.784	.808	.832	.856	.879	.901	.920	.942	.965	.981	1	1.02	1.03	1.04
30	.701	.725	.748	.772	.796	.819	.844	.865	.887	.905	.928	.949	.966	.985	1	1.02	1.02
32	.690	.714	.736	.760	.784	.806	.830	.853	.874	.891	.914	.934	.951	.970	.985	1	1.01
[a]32.8	.685	.708	.730	.754	.778	.800	.824	.846	.864	.885	.906	.926	.943	.962	.977	.992	1

[a] Green.

TABLE 30.—*Reduction factors for modulus of elasticity of chestnut.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.[a]	26.
2	1	1.06	1.11	1.16	1.21	1.26	1.30	1.34	1.38	1.43	1.47	1.50	1.54
4	.946	1	1.05	1.10	1.15	1.19	1.23	1.27	1.31	1.35	1.39	1.42	1.46
6	.902	.953	1	1.05	1.09	1.14	1.17	1.21	1.25	1.29	1.32	1.35	1.39
8	.861	.910	.955	1	1.04	1.08	1.12	1.16	1.19	1.23	1.26	1.29	1.33
10	.826	.873	.916	.960	1	1.04	1.07	1.11	1.14	1.18	1.21	1.24	1.27
12	.795	.840	.881	.923	.962	1	1.03	1.07	1.10	1.14	1.17	1.19	1.22
14	.770	.813	.853	.894	.931	.968	1	1.03	1.06	1.10	1.13	1.16	1.18
16	.744	.786	.825	.865	.901	.936	.968	1	1.03	1.06	1.09	1.12	1.15
18	.722	.764	.800	.839	.875	.908	.938	.970	1	1.03	1.06	1.09	1.11
20	.700	.740	.776	.814	.848	.881	.910	.940	.969	1	1.03	1.05	1.08
22	.681	.720	.755	.791	.825	.857	.885	.915	.942	.974	1	1.02	1.05
[a]24	.665	.703	.737	.773	.806	.837	.865	.894	.920	.950	.976	1	1.02
26	.650	.687	.720	.755	.786	.818	.845	.873	.900	.928	.954	.977	1

[a] Green.

TABLE 31.—*Reduction factors for stress at elastic limit of longleaf pine.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.												
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.[a]
2	1	1.13	1.31	1.53	1.75	1.99	2.20	2.39	2.54	2.70	2.85	2.99	3.14
4	.882	1	1.15	1.35	1.54	1.75	1.94	2.11	2.25	2.39	2.52	2.64	2.77
6	.767	.867	1	1.17	1.34	1.52	1.69	1.83	1.95	2.07	2.18	2.29	2.41
8	.656	.742	.856	1	1.15	1.30	1.44	1.57	1.67	1.77	1.87	1.96	2.06
10	.572	.648	.746	.872	1	1.13	1.26	1.37	1.45	1.54	1.63	1.71	1.80
12	.503	.570	.657	.768	.881	1	1.11	1.20	1.28	1.36	1.44	1.51	1.58
14	.455	.515	.594	.694	.795	.904	1	1.09	1.16	1.23	1.30	1.36	1.43
16	.419	.475	.547	.639	.733	.832	.921	1	1.07	1.13	1.19	1.25	1.32
18	.393	.445	.513	.600	.688	.781	.865	.938	1	1.06	1.12	1.17	1.24
20	.370	.420	.485	.565	.648	.735	.814	.884	.941	1	1.05	1.11	1.16
22	.351	.397	.458	.535	.614	.697	.771	.838	.893	.948	1	1.05	1.10
24	.335	.379	.437	.510	.585	.665	.735	.799	.851	.904	.954	1	1.05
[a]26	.318	.361	.415	.486	.556	.633	.700	.760	.810	.860	.908	.951	1

[a] Green.

TABLE 32.—*Reduction factors for stress at elastic limit of red spruce.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent.																
	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	30.5 [a]	32.
2	1	1.08	1.20	1.35	1.50	1.67	1.83	1.97	2.14	2.29	2.47	2.59	2.75	2.92	3.08	3.11	3.16
4	.924	1	1.11	1.25	1.39	1.54	1.69	1.82	1.98	2.12	2.28	2.40	2.54	2.69	2.85	2.87	2.92
6	.833	.901	1	1.12	1.25	1.39	1.52	1.64	1.78	1.91	2.05	2.16	2.29	2.43	2.57	2.59	2.63
8	.741	.802	.890	1	1.21	1.24	1.35	1.46	1.59	1.70	1.83	1.92	2.04	2.16	2.28	2.30	2.34
10	.665	.620	.799	.897	1	1.11	1.20	1.31	1.42	1.52	1.64	1.73	1.83	1.94	2.05	2.07	2.10
12	.599	.649	.720	.808	.901	1	1.09	1.18	1.28	1.37	1.47	1.55	1.65	1.75	1.85	1.86	1.89
14	.548	.593	.659	.740	.825	.915	1	1.08	1.17	1.26	1.35	1.42	1.51	1.60	1.69	1.70	1.73
16	.508	.550	.610	.685	.764	.848	.925	1	1.09	1.16	1.25	1.32	1.40	1.48	1.56	1.58	1.60
18	.467	.505	.561	.630	.702	.780	.851	.920	1	1.07	1.15	1.21	1.28	1.36	1.44	1.45	1.41
20	.436	.412	.524	.589	.657	.728	.796	.860	.935	1	1.08	1.13	1.20	1.27	1.34	1.36	1.38
22	.406	.440	.487	.547	.610	.678	.740	.800	.870	.930	1	1.05	1.12	1.18	1.25	1.26	1.28
24	.386	.417	.463	.520	.580	.644	.703	.760	.826	884	.950	1	1.06	1.12	1.19	1.20	1.22
26	.363	.393	.436	.490	.546	.607	.663	.715	.778	.832	.895	.942	1	1.06	1.12	1.13	1.15
28	.343	.371	.412	.463	.516	.572	.625	.676	.735	.786	.845	.889	.945	1	1.06	1.06	1.08
30	.325	.351	.390	.438	.488	.542	.592	.640	.695	.744	.800	.842	.894	.946	1	1.01	1.03
[a] 30.5	.321	.348	.386	.434	.484	.537	.586	.634	.689	.737	.792	.834	.885	.937	.990	1	1.02
32	.317	.343	.380	.427	.476	.529	.577	.624	.678	.725	.780	.821	.811	.924	.975	.985	1

[a] Green.

TABLE 33.—*Reduction factors for stress at elastic limit of chestnut.*

[Bending tests.]

TO— Moisture per cent.	FROM— Moisture per cent. 2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	27.2 [a]	28.
2	1	1.11	1.22	1.33	1.44	1.53	1.65	1.76	1.90	2.00	2.12	2.25	2.41	2.49	2.54
4	.899	1	1.10	1.19	1.29	1.38	1.48	1.58	1.70	1.80	1.90	2.03	2.16	2.23	2.29
6	.820	.913	1	1.09	1.18	1.26	1.35	1.45	.55	1.64	1.74	1.85	1.97	2.04	2.09
8	.753	.837	.918	1	1.08	1.16	1.24	1.33	1.43	1.51	1.59	1.70	1.81	1.87	1.92
10	.697	.775	.850	.926	1	1.07	1.15	1.23	1.32	1.39	1.48	1.57	1.68	1.73	1.77
12	.652	.725	.795	.866	.935	1	1.07	1.15	1.23	1.30	1.38	1.47	1.57	1.62	1.66
14	.607	.675	.740	.806	.871	.931	1	1.07	1.15	1.21	1.29	1.37	1.46	1.51	1.54
16	.568	.631	.692	.754	.814	.871	.935	1	1.07	1.13	1.20	1.28	1.37	1.41	1.44
18	.528	.588	.644	.701	.758	.810	.870	.931	1	1.06	1.12	1.19	1.27	1.31	1.34
20	.500	.556	.610	.665	.718	.767	.824	.881	.947	1	1.06	1.13	1.20	1.24	1.27
22	.472	.525	.575	.627	.677	.724	.778	.832	.894	.943	1	1.06	1.14	1.17	1.20
24	.444	.494	.541	.590	.637	.681	.731	.782	.840	.887	.940	1	1.07	1.10	1.13
26	.416	.462	.506	.552	.596	.638	.685	.782	.787	.831	.881	.936	1	1.03	1.06
27.2	.402	.448	.490	.534	.571	.617	.664	.708	.761	.804	.853	.906	.967	1	1.02
[a] 28	.393	.438	.479	.522	.564	.603	.648	.693	.745	.786	.833	.886	.946	.978	1

[a] Green.

APPENDIX A.

I. Formulas Used in the Calculations.

[For nomenclature, see p. 113.]

Bending.

Deflections read to 0.01 inch. Approximate speed of machine 0.1 inch per minute.

Modulus of rupture .... $R=\frac{3Wl}{2bh^2}=$ pounds per square inch.

Stress on extreme fibers at elastic limit .... $f=\frac{3W_1l}{2bh^2}=$ pounds per square inch.

Modulus of elasticity .... $E=\frac{W_1l^3}{4dbh^3}=$ pounds per square inch.

Rate of fiber stress .... $Z=\frac{f}{t}=$ pounds per square inch per minute.

Elastic resilience in inch-pounds of work per 1 cubic inch of volume. $K_b=$ Area of stress diagram below elastic limit, divided by volume of specimen between supports $=\frac{W_1d}{2V}$ or $\frac{f^2}{18E}$.

Total resilience per cubic inch .... $K_{1b}=$ Area of stress diagram below the maximum point divided by the volume between supports.

Compression Parallel to Grain.

Deflections read to 0.001 inch. Approximate speed of machine 0.01 inch per minute

Crushing strength .... $C=\frac{W}{A}=$ pounds per square inch.

Stress at elastic limit .... $F=\frac{W_1}{A}=$ pounds per square inch.

Modulus of elasticity .... $E_c=\frac{W_1l}{dA}=$ pounds per square inch.

Rate of fiber stress .... $Z=\frac{F}{t}=$ pounds per square inch per minute.

Elastic resilience in inch-pounds of work per cubic inch of volume. $K_c=$ Area of stress diagram below the elastic limit, divided by the volume in cubic inches, $\frac{W_1d}{2V}=\frac{F^2}{2E_c}$.

Total resilience per cubic inch .... $K_{1c}=$ Area of stress diagram below maximum point, divided by volume.

SHEARING.

Approximate speed of machine, 0.01 inch per minute. Shearing strength $= \frac{W}{A} =$ pounds per square inch.

SPEED OF MACHINE.

Rate of deflection $= \frac{d}{t} =$ inch per minute.

NOMENCLATURE.

The following nomenclature is used throughout this bulletin:

C = Crushing strength parallel to grain.
E_c = Modulus of elasticity in compression parallel to grain.
F = Elastic limit in compression parallel to grain.
R = Modulus of rupture in bending.
E = Modulus of elasticity in bending.
f = Stress at elastic limit in bending.
St = Shearing strength tangential to annual rings.
Sr = Shearing strength radial to annual rings.
Xt = Crushing strength at right angles to grain, tangential to annual rings.
Xr = Crushing strength at right angles to grain, perpendicular to annual rings.

All the above are expressed in pounds per square inch of actual area.

W = Maximum load in pounds.
W_1 = Load at elastic limit in pounds.
l = Length in inches (in beams = span).
d = Amount of deflection in inches.
A = Area of cross section in square inches.
b = Breadth of beam in inches.
h = Depth of beam in inches.
V = Volume in cubic inches, under stress.
t = Time in minutes.

II. Description of Special Studies and Subordinate Investigations.

1. The Fiber-Saturation Point

For the purpose of determining the fiber-saturation point, which is the critical moisture degree at which the strength first begins to increase in drying, a number of special compression tests were made on small pieces.

Strips about three-fourths inch square were cut from various planks, care being taken in selecting them so as to have each strip uniform throughout and of straight grain. These strips were then cut up into a series of eight consecutive blocks, 1½ inches in length, for compression parallel to grain tests, one set being tested green and the other sets at various stages of drying. The pieces were tested for ultimate crushing strength, and thin moisture disks were cut from the portion of failure, the moisture per cents being determined in the usual manner. The individual points were plotted upon cross-section paper and a curve was drawn for each series. These curves are shown in fig. 18.

The object of using such small test specimens was in order to facilitate the drying process and obtain greater uniformity in the transverse distribution of moisture. The pieces were treated in such a manner as to permit of drying from the ends only, thus assuring the desired condition as nearly as possible. By using small specimens any increase in strength is as truly indicated as would be the case with large pieces. No attempt was made to measure the deflections in these tests, since it is reasonable to suppose that the increase in stiffness takes place coordinately with the increase in ultimate strength. The compression test parallel to grain was chosen on account of its being by far the most reliable as well as the most convenient to make.

Five series each of longleaf pine, spruce, chestnut, and loblolly pine were tested, making 160 tests in all. The last named were conducted at the testing station of the Bureau of Forestry in connection with the Louisiana Purchase Exposition. From the curves of these tests given in fig. 18 it will be seen that as the wood dried, no change in strength occurred until a definite moisture degree was reached, when it began to increase rapidly. This is the fiber-saturation point, as explained on page 82.

The curves show the following results:

	Range of specific gravity.	Fiber-saturation point.	
		Moisture.	Average.
		Per cent.	*Per cent.*
Longleaf pine	0.58 to 0.67	24 to 26	24.7
Spruce	.37 to .42	28 to 35	30.8
Chestnut	.42 to .54	23 to 28	25.4
Loblolly pine sapwood		23 to 29	25.2
Red gum [a]	.47 to .52		25.0
Red fir [a]			23.0
Loblolly pine sapwood [a]	.45 to .50		24.0
Loblolly pine heartwood [a]			22.5

[a] From recent tests at Yale Laboratory.

2. Loss of Inherent Strength Due to Drying.

In addition to the reabsorption tests of the regular series, 147 special tests were made upon small pieces, to determine the effect of the drying process upon the wood fiber. The pieces were prepared in the usual "series" plan, one set being tested green, one after drying, and one set after drying and resoaking.

Five strips each of longleaf pine, spruce, and chestnut seven-eighths inch square were cut into 1½-inch lengths and tested in compression parallel to grain. A corresponding number of specimens were cut 14 inches long and tested as beams with 1 foot span.

Each series consisted of 4 sets, lettered *a, b, c, d*. Of the compression tests, set *a* was tested green, set *b* was dried in a steam-jacketed oven with live steam allowed to escape

inside (differing in this respect from the usual treating cylinder process, in which the wood does not lose, but rather gains, moisture) for 3 days of about 8 hours each, then resoaked 15 days. Set c was dried in air at about 208° F. for 3 days, then resoaked 20 days. Set d was dried the same as a, and tested at once. Of the beams, set a was tested green; set b dried

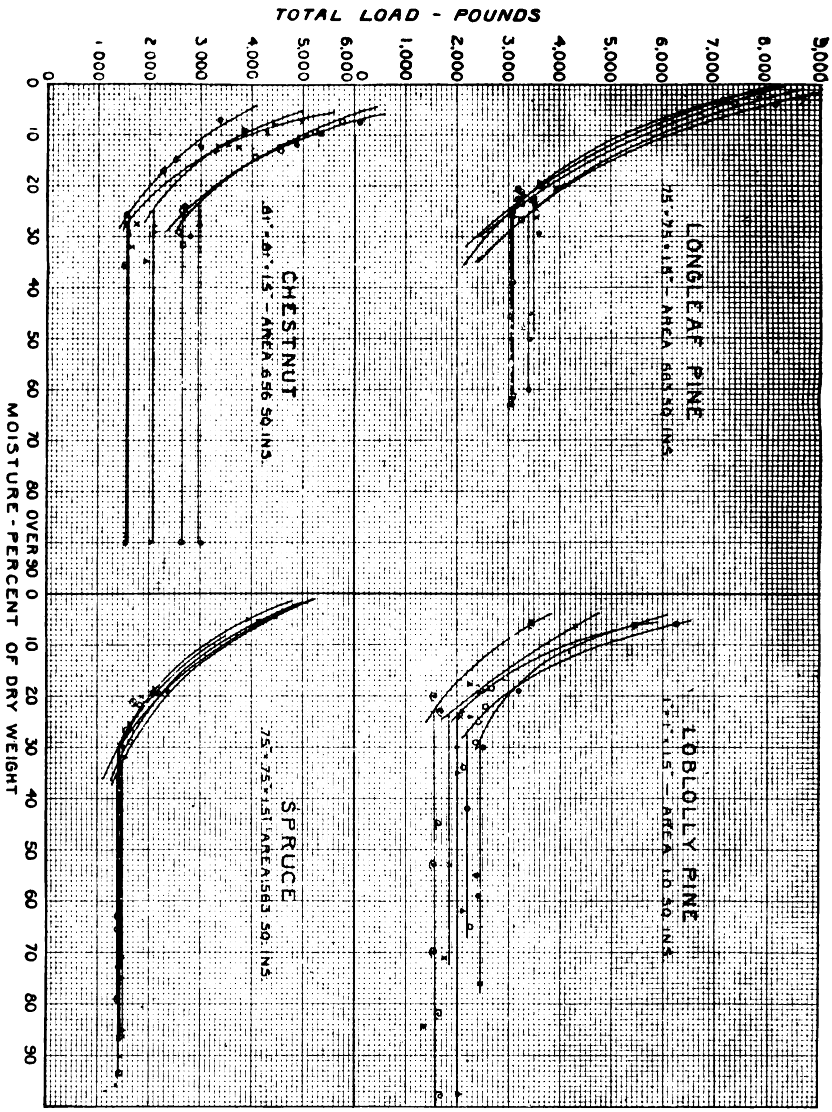

Fig. 18.—Curxes showing how the fiber-saturation point is determined.

in steam as above 4 days during the daytime and shut up tight over night, then resoaked 17 days. Set c was dried in hot air 4 days, then resoaked 19 days. Set d was dried in steam the same as b, but was tested at once.

TABLE 34.—*Loss of inherent strength due to drying.*

Special tests upon small pieces in compression and bending, showing the effect of the drying process in steam and in dry air upon the strength, by comparison of the results with the original strength when green, after drying and then resoaking the test specimens.

[Each value is the average of five tests.]

Species.	No. of set.	Treatment.	Compression: Crushing strength.	Compression: Ratio to strength, green.	Compression: Moisture.	Bending: Maximum center load.	Bending: Ratio to strength, green.	Bending: Moisture.
			Lbs. per sq. inch.		*Per cent.*	*Pounds.*		*Per cent.*
Longleaf pine.	a	Tested green	5,520	1.00	26.0	343	1.00	28.0
	b	Steamed and resoaked.	4,550	.82	34.0	389	1.13	28.0
	c	Hot air and resoaked	4,710	.85	38.0	322	.94	35.0
	d	Steamed	12,100	2.19	3.9	713	2.08	4.9
		Calculated [a]	15,600	2.83	3.9	781	2.26	4.9
Spruce	a	Tested green	2,660	1.00	39.0	206	1.00	44.0
	b	Steamed and resoaked.	2,090	.79	55.0	185	.90	42.0
	c	Hot air and resoaked	2,280	.86	61.0	158	.77	46.0
	d	Steamed	6,860	2.58	6.9	445	2.16	5.4
		Calculated [a]	8,310	3.13	6.9	544	2.64	5.4
Chestnut.	a	Tested green	3,210	1.00	100.0	249	1.00	110.0
	b	Steamed and resoaked.	2,560	.80	74.0	204	.82	55.0
	c	Hot air and resoaked	2,630	.82	94.0	208	.84	75.0
	d	Steamed	8,090	2.52	3.5	194	.78	35.0
		Calculated [a]	8,910	3.81	3.5	249	1.00	35.0

[a] This value is for comparison with sets designated as "d," being calculated for the same moisture degree as the latter from the sets "a," on the basis of the regular moisture curves.

The average results for each set are given in Table 34, together with the factor of relation to original green strength. The moisture per cent was determined by the usual method of cutting a thin disk from the region of failure.

In addition to the above, three series of compression tests were also made upon chestnut, 1 inch square and 2 inches long 4 series upon longleaf pine, and 1 upon spruce. Of the chestnut, set 1 was tested green; set 2 was kiln-dried 12 days, then oven dried at about 203° F. for 1 day, and finally soaked 36 days, until the original weight had been resumed; set 3 was treated the same as the last, except that they were subjected to a high vacuum during oven drying; set 4 was treated the same as set 3, but not resoaked. Of the longleaf pine and spruce, set 1 was soaked one month; set 2 was kiln-dried 20 days at 130° F., then soaked 16 days; set 3 same as set 2, but not soaked. The averaged results are shown in Table 35.

TABLE 35.—*Loss in strength due to kiln-drying, by comparison of the results with the original wet condition, after drying and then resoaking the test specimens.*

[Compare with Table 34.]

Species.	No. of set.	Treatment.	Compression: Strength.	Compression: Ratio to strength, green.	Compression: Number of tests averaged.	Compression: Moisture condition.
			Lbs. per sq. inch.			
Longleaf pine	1	Soaked 1 month	4,540	1.00	4	Wet.
	2	Kiln dried and resoaked	4,311	.95	4	Wet.
	3	Kiln dried	11,430	2.51	4	Dry.
Spruce	1	Soaked 1 month	2,310	1.00	1	Wet.
	2	Kiln dried and resoaked	2,010	.87	1	Wet.
	3	Kiln dried	7,240	3.13	1	Dry.
Chestnut	1	Tested green	2,232	1.00	3	Wet.
	2	Oven dried and resoaked	2,135	.96	3	Wet.
	3	Vacuum dried and resoaked	2,050	.90	3	Wet.
	4	Vacuum dried	9,000	4.03	3	Very dry.

From the foregoing results it is evident that a decided loss in inherent strength is produced by drying, even at comparatively mild temperatures, and especially so when the wood is steamed.[a] That this loss is not entirely due to the soaking process is shown by study No. 5 on page 120, and probably it is not at all due to the resoaking. In general, the loss due to steaming appears to be about 20 per cent, and that due to drying in air at the same temperature slightly less.

3. Casehardening.

Considerable difficulty was found in drying the chestnut wood uniformly, as even in steam the outer surface would dry first, leaving the interior wet and containing free water. Dried more rapidly, the wood "casehardens," or forms a hard, dry shell on the outside, while the interior still retains most of its original water. This dry shell resists the transpiration of the interior moisture and retards the drying operation, besides causing severe strains in the fibers. When the interior finally drys it frequently causes so great internal strain that checks open up on the inside of the block which are invisible on the surface. (See Pl. IV.)

Chestnut wood is peculiarly useful in studying the manner in which drying takes place, since all portions containing any free water turn black at once when brought in contact with iron or rubbed over with ever so little iron rust, whereas the portions which have no free water remain uncolored. This permits the moisture distributions to be seen directly. In fig. 2, Pl. IV, is shown the moisture distribution in a chestnut strip 2 by 2 by 40 inches, in successive sections from one end to the middle. The first section at the left is cut one-fourth inch from the end, the next one-half inch, the next 1 inch, and all the others 1 inch apart. This strip was thoroughly wet when placed in the kiln, where it remained 7 days in moist air at 100° to 130° F. The illustration shows the casehardening very clearly.

In order to determine the relation of casehardening to the moisture-strength law, a number of tests were performed upon chestnut purposely casehardened. These consisted of seven series of beams of the regular size and an equal series of end-compression pieces cut therefrom, each series made up of three sets, *a*, *b*, and *c*, tested at three stages of drying, respectively. (See fig. 1, Pl. IV) The material used was from the same planks as the regular tests, in order that the results might be compared directly with the regular tests. Each beam after testing was cut up, thus:

C is the compression block subsequently tested; *a* is a whole disk at point of failure, dried in the usual manner; *x* is another disk cut up into an outer layer and an inner portion, the former containing only the dry and the latter only the wet portion of the disk.

The result is best shown by the curves, figs. 19 and 20.[b]

If these values be plotted in the ordinary way, using disk *a* for the moisture, the result will be a curve altogether too high, and totally obscuring the fiber-saturation point, as explained on page 83. On the other hand, if the moisture be based on the outer part of disk *x*, the curve will fall somewhat too low, although very much nearer to the curve of uniform distribution of moisture, especially in the case of beams where it is the outer

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[a] A long series of tests made at the timber-testing laboratory of the Forest Service at the Louisiana Purchase Exposition on loblolly pine ties which had been subjected to the steaming process in a closed cylinder show that the loss of strength due to steaming is a direct factor of the steam pressure, as follows:

Original strength 100.
Strength after 10 pounds steam pressure for 4 hours, 89.
20 pounds steam pressure for 4 hours, 84.
30 pounds steam pressure for 4 hours, 75.
40 pounds steam pressure for 4 hours, 76.
50 pounds steam pressure for 4 hours, 68.
100 pounds steam pressure for 4 hours, 41.

[b] In these two figures, the casehardened values shown have all been corrected so as to be comparable to the strength values of the regular tests.

fibers which count the most in the strength. The moisture of the interior part of disk x is of course far greater than the average of the section given by disk a, and would make the resulting curve altogether too high.

In figs. 19 and 20 these casehardened curves are given in comparison with the regular curves based on uniformly distributed moisture, the moisture per cent of the former being that obtained from the whole cross section or disk a. This comparison indicated very strikingly that the respective strength values, for a given moisture degree, obtained in this

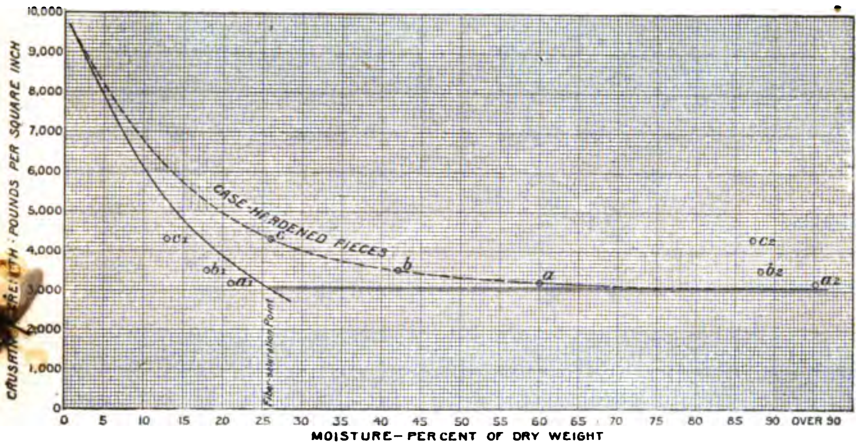

FIG. 19.—Effect of casehardening upon the form of the moisture-strength curve for compression parallel to grain. Chestnut.

way (that is, by an average of the whole cross section), though they represent the general case in ordinary conditions, do not show the true relations. In the figures the casehardened curve is indicated in dashed lines, while the corresponding curve for evenly distributed moisture is given in full lines. Points a, b, c, are the average values based upon disks a

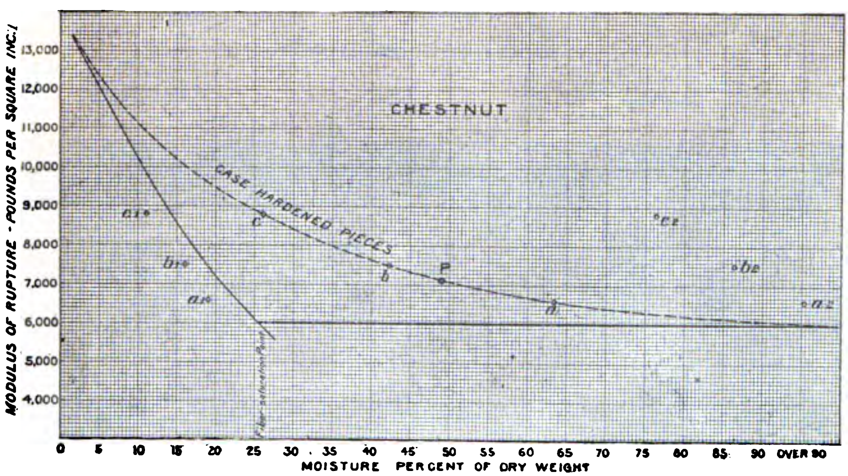

FIG. 20.—Effect of casehardening upon the form of the moisture-strength curve for bending.

(from Table 36); points a', b', c', the same based upon the outer parts of disks x, and a'', b'', c'', based upon the inner parts of disks x. Point P in fig. 20 is obtained from five beam tests of the regular series, Table 7, which were unintentionally casehardened, and it will be noticed how closely it falls upon the casehardened curve.

Table 36.—*Distribution of moisture, corresponding strength values, and comparison of the latter with those for uniformly distributed moisture at the same respective moisture degree, for three stages of casehardening, chestnut.*

The moisture condition of these tests is illustrated in fig. 1, Plate IV.

[Each figure is the average of six tests.]

Test.	No. of set.	Average width of shell.	Average moisture of whole disk *a*.	Moisture of outer and inner portions. disk *x*. Outside.	Inside.	Total load.	Modulus of rupture, *R*.	Compression. *C*.	Strength value corresponding to disk *a*, if moisture were uniformly distributed.	Increase of casehardened value above the corresponding uniform-moisture value.
		Inches.	*Per ct.*	*Per ct.*	*Per ct.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per ct.*
Bending	a	0.22	63	19	100	832	5,831	....	5,500	6.0
	b	.38	42	16	86	973	6,881	....	5,500	25.1
	c	.54	26	11	76	1,150	7,867	....	5,600	40.5
Compression	a	.20	60	21	96	10,910	....	2,728	2,600	4.9
	b	.35	42	18	88	12,083	....	3,131	2,600	20.4
	c	.54	26	13	87	14,593	....	3,810	2,600	46.6

4. Effect of Length of Time in Soaking.

GREEN WOOD.

Three series each, of chestnut, ash, and maple were tested, using native, thoroughly green wood. This consisted of five sets of compression pieces, three-fourths-inch square, and 1½ inches long, 120 tests in all. They were soaked in cold water various lengths of time. The results given in Table 37 show no decided effect upon the strength, from which it may be concluded with reasonable certainty that soaking green wood in cold water does not change its strength.

Table 37.—*Effect upon the crushing strength of green wood, of the length of time it is soaked in cold water.*

[Each value is the average of three tests.]

No. of set.	Chestnut. Number of days soaked.	Strength.	Duration of test.	Moisture.	Ash. Number of days soaked.	Strength.	Duration of test.	Moisture.	Hard maple. Number of days soaked.	Strength.	Duration of test.	Moisture.
		Lbs. per sq. in.	*Min.*	*Per ct.*		*Lbs. per sq. in.*	*Min.*	*Per ct.*		*Lbs. per sq. in.*	*Min.*	*Per ct.*
1	0	2,840	1.4	103	0	3,190	2.1	83.1	0	4,640	2.1	49.4
2	13	2,690	2.1	133	11	3,220	2.1	106	11	4,790	1.7	71.9
3	19	2,660	2.1	145	21	3,430	1.6	110	21	4,940	1.9	81.2
4	25	2,720	2.0	150	42	3,320	1.3	117	42	4,840	1.7	90.3
5	96	2,730	1.4	160	86	3,470	2.9	116	86	4,680	1.7	85.9

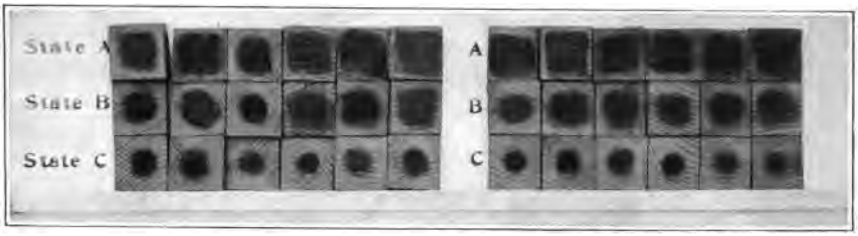

FIG. 1.—THREE DEGREES OF DRYING. SECTIONS OF THE SPECIMENS USED IN OBTAINING FIGS. 19 AND 20.

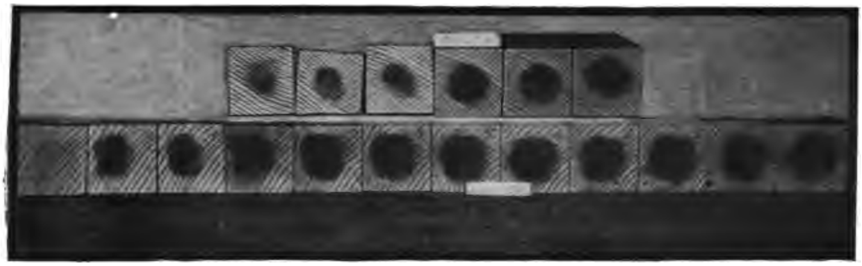

FIG. 2.—PROGRESS OF DRYING THROUGHOUT THE LENGTH OF A CHESTNUT BEAM. THE BLACK SPOT INDICATES FREE WATER IN THE PORES OF THE WOOD.

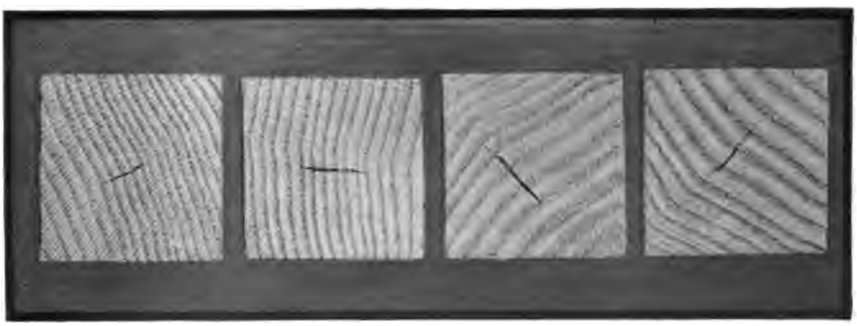

FIG. 3.—INTERNAL CHECKING DUE TO CASEHARDENING. CHESTNUT.

EFFECT OF CASEHARDENING IN DRYING.

AIR-DRY WOOD.

Five series each of longleaf pine, spruce, and chestnut were prepared from air-dried material. Each series consisted of eight compression pieces three-fourths inch square, and 1½ inches long, cut successively from the same strip, which were soaked various lengths of time. Sets Nos. 1 and 8, taken from opposite ends of the strips, were tested air-dry, in order to determine the amount of variation in strength between the two extremities of the same strips. Set 3 was soaked in warm water, and set 4 was boiled after soaking in warm water.

The soaking in cold water was carried on in a glass jar in the room, at about 54° to 64° F. The results are given in the following table, from which it appears that prolonged soaking slightly increases the strength. Note, however, that although set 8 is also stronger than set 1, there is still an increase manifest when this is taken into account, as shown by the last columns for each species in the table. (See discussion of this subject in the text, page 84).

TABLE 38.—*Effect upon the crushing strength of air-dried wood, of the length of time it is soaked in cold water, and also in hot and in boiling water.*

[Each value is the average of five tests.]

No. of set.	Treatment.	Number of days soaked.	Longleaf pine. Strength.	Longleaf pine. Moisture.	Longleaf pine. Increase in strength above No. 2.[a]	Spruce. Strength.	Spruce. Moisture.	Spruce. Increase in strength above No. 2.	Chestnut. Strength.	Chestnut. Moisture.	Chestnut. Increase in strength above No. 2.
			Lbs. pr. sq. in.	*Per ct.*	*Per ct.*	*Lbs. pr. sq. in.*	*Per ct.*	*Per ct.*	*Lbs. pr. sq. in.*	*Per ct.*	*Per ct.*
1	Air dry	0	7,220	14.0	....	3,740	18.4	....	3,260	20.4	....
8	do	0	7,350	14.1	....	4,050	17.5	....	3,160	20.7	....
2	Soaked cold	11	4,170	58.0	0	2,670	86.0	0	2,540	110.0	0
5	do	19	4,200	53.0	.47	2,720	74.0	−0.73	2,710	110.0	7.1
7	do	30	4,380	71.0	3.5	2,820	115.0	1.1	2,750	123.0	9.1
6	do	60	4,440	83.0	5.7	2,980	137.0	8.0	2,740	145.0	8.7
3	Soaked hot, 126° F	10	3,650	59.0	−12.9	2,380	92.0	−35.3	1,740	117.0	−31.2
4	Soaked hot 12 days then boiled 14 hours	......	2,900	96.0	−31.3	1,670	139,0	−38.4	1,150	147.0	−54.6

[a] The third column for each species gives the increase of strength above the mean in per cent of the same, on the assumption that the average of the inherent strength increased throughout the length of the strips as shown by sets No. 1 and No. 8 (after reducing the latter to equivalent moisture conditions). The increase of set No. 8 over set No. 1 after correcting for moisture is, longleaf pine 2.49 per cent, spruce 4.55 per cent, chestnut 1.23 per cent. Negative sign indicates *decrease* in strength.

5. EFFECT OF SOAKING DRY WOOD AND THEN REDRYING IN AIR.

For this study five strips each of the three species were carefully prepared three-fourths inch square from thoroughly air-dry material, and each cut into five consecutive compression test pieces 1½ inches long, making 75 pieces in all. Set 1 was tested air-dry, set 2 soaked, at the temperature of the room for over a month, then hung up in the air of the room for several weeks until the pieces had resumed the original weights or less. Set 3 was soaked in hot water for thirty-seven days and finally boiled for five or six hours, then air-dried as the former for several weeks. Set 4 was treated as set 2, except that it was soaked about three times as long—three months—then dried for one month. Set 5 was soaked about five weeks (except the pine, two months) and tested wet without drying. The results given in the following table show a decided loss in the case of the boiled pieces, and apparently some also in the others.

TABLE 39.—*Effect of the soaking process upon the compression strength, by a comparison with the original strength values of the air-dry material of the results after soaking air-dried wood in cold and in hot water and then redrying in the air.*

[Each value is the average of five tests.]

Species.	No. of set.	Treatment.	Original weight of piece.	Weight when soaked.	Weight at test.	Moisture at test.	Strength.	Strength reduced to same moisture.
			Grams.	*Grams.*	*Grams.*	*Per cent.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*
Longleaf pine.	1	Dry, untreated.........	10.9	....	10.9	10.1	10,800	10,800
	2	Soaked 6 weeks, dried 6 weeks.	11.0	16.8	10.7	10.4	10,700	10,920
	3	Soaked warm 37 days, boiled 1 day, dried 20 days.	11.0	14.5	10.7	8.6	10,600	9,710
	4	Soaked 92 days, dried 21 days.	11.1	17.5	10.7	9.2	11,550	10,910
	5	Soaked 74 days.........	11.2	16.8	16.8	81.0	5,810	....
Spruce....	1	Dry, untreated.........	6.5	....	6.4	12.1	6,320	6,320
	2	Soaked 39 days, dried 13 days.	6.3	13.2	6.1	11.0	6,400	6,060
	3	Soaked warm 37 days, boiled 1 day, dried 14 days.	6.3	12.7	6.0	9.8	6,370	5,730
	4	Soaked 92 days, dried 21 days.	6.4	15.0	6.0	9.4	6,990	6,120
	5	Soaked 40 days.........	6.4	12.9	12.9	93.0	2,670	....
Chestnut.	1	Dry, untreated.........	6.9	....	6.8	11.7	6,490	6,490
	2	Soaked 39 days, dried 21 days.	6.9	13.8	6.5	9.5	6,850	6,120
	3	Soaked warm 37 days, boiled 1 day, dried 20 days.	6.9	14.1	6.4	9.8	6,660	6,080
	4	Soaked 92 days, dried 39 days.	7.0	15.2	6.4	8.8	6,700	5,780
	5	Soaked 40 days.........	7.1	14.0	14.0	11.2	3,340	....

6. EFFECT OF TEMPERATURE UPON THE STRENGTH OF WET WOOD.

EFFECT OF HEAT.

It has been pointed out on page 84 that the fiber-saturation point is greatly affected by the temperature; that heating the water in which the wood is soaking reduces the strength.

Heating and boiling.—A number of compression and bending tests were made in order to determine directly the relation of the various strength factors at different temperatures. The usual sizes, 2 by 2 inches in cross section, were used for these tests, and the comparisons made upon pieces cut from the same strip. Thoroughly water-soaked material was used for the basis, some specimens were tested cold, others warmed for over a week in water at about 127° F., and the rest warmed and then boiled for a number of hours.

In Table 40 each value is the average of about two tests, except those contained in parenthesis, which were substituted from the regular tests.

The weakening effect of the warmer temperatures is very marked indeed. In fact, boiling produces a condition of great pliability, especially of the hardwoods; hence the reason for boiling the wood which is to be permanently bent into various shapes. When the piece which has been thus bent dries in that position it rigidly retains the shape of the bend, although the strength has been permanently somewhat decreased by the boiling.

TABLE 40.—*Effect of soaking in hot and in boiling water upon the strength and stiffness, as compared with soaking in cold water.*

Species.	Treatment.	Compression parallel to grain of pieces 2" x 2" x 5.75".			Bending of pieces 2" x 2", span 36".		
		Crushing strength, C.	Stress at elastic limit, F.	Modulus of elasticity, E_c.	Modulus of rupture, R.	Stress at elastic limit, f.	Modulus of elasticity, E.
		Lbs. per sq. inch.	*Lbs. per sq. inch.*	*1,000 lbs. per sq. in.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 lbs. per sq. in.*
Longleaf pine.	Green or soaked, cold (values substituted from other tests).	(5,000)	(3,900)	(1,423)	....	....	....
	Soaked cold 10 months, warmed 127° F. 10 days.	4,240	3,570	1,320	....	....	....
	Same as last, then boiled 8 hours.	3,065	2,545	971	....	....	....
Spruce....	Soaked cold 10 months and exposed to freezing temperatures; cut from middle of strip.	2,580	1,850	625	5,377	3,563	1,169
	Same as last, then warmed 127° F. 9 days.	1,920	1,475	594	5,070	2,890	1,130
	Same as last, finally boiled; compression 18 hours, bending 8 hours.	1,430	930	465	3,605	2,060	867
Chestnut..	Green or soaked, cold (values substituted from other tests).	(3,170)	(2,441)	(742)	(6,345)	(3,638)	(1,072)
	Green wood, soaked cold 7 days, then warmed 8 days.	1,845	1,115	507	4,505	2,380	712
	Same as last, finally boiled 8 hours.	1,125	490	265	2,300	670	316

EFFECT OF COLD.

Table 41 gives the results of some compression tests of the regular size (and some 3 by 3 inch sizes) made upon both wet and dry wood at temperatures considerably below the freezing point, and compared with similar tests upon adjacent pieces of the same material made at the ordinary room temperature. An examination shows a decided increase in both the strength and stiffness of the frozen pieces, excepting the very dry wood.

A summary of the damp and wet pieces gives the following results:

	Number of tests.	Moisture.	Crushing strength.	Modulus of elasticity.
		Per cent.	*Pounds per sq. in.*	*Pounds per sq. in.*
Longleaf pine:				
Cold..........	2	23	6,440	1,418,000
Warm..........	2	24	5,750	1,360,000
Spruce:				
Cold..........	3	27	4,060	894,000
Warm..........	3	22	3,923	753,000
Chestnut:				
Cold..........	4	68	3,180	708,000
Warm..........	4	72	2,622	553,000

This result is in accord with what was naturally expected from the fiber-saturation point theory, but it may also be due in part to the solidifying of the free water in the pores of the wood, provided there is any such free water.

TABLE 41.—*Effect of freezing temperatures upon strength and stiffness under compression, as compared with ordinary temperatures.*

Species.	No. of piece.	Previous treatment.	Condition and temperature.		Total load.	Crushing strength, *C*.	Stress at elastic limit, *F*.	Modulus of elasticity, E_c.	Moisture.
				° F.	*Lbs.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 lbs. per sq. in.*	*Per cent.*
Longleaf pine.	A-1	Soaked 1½ years; chopped out of solid ice and tested immediately.	Wet....	Frozen, 14.	59,890	6,580	5,280	1,390	23.0
	B-1		Wet....	....do....	57,250	6,300	5,500	1,445	23.0
	A-2	Same, kept in room, wrapped in oil paper 3 days prior to testing.	Wet....	Warm, 45.	51,860	5,700	4,500	1,170	24.4
	B-2		Wet....	....do....	52,630	5,800	4,420	1,550	24.4
	C-3	Air-dried in room 1 year.	Dry.....	Frozen, 19	50,500	15,870	11,900	2,140	......
	C-4	....do..............	Dry.....	Warm, 57.	49,000	15,810	11,600	2,660	......
Spruce....	D-1	Thoroughly soaked...	Wet....	Frozen, 17.	16,075	4,000	1,990	1,190	28,7
	D-2	....do..............	Wet....	Warm, 68.	14,645	3,610	2,710	709	22.5
	E-3	Partly dry...........	Partly..	Frozen, 17.	13,775	3,530	2,050	737	(21.0)
	E-4	....do..............	Partly..	Warm, 68.	12,350	3,220	1,820	524	20.7
	F-1	Thoroughly soaked, cut out of ice.	Wet....	Frozen, 17.	17,660	4,650	2,900	756	31.7
	F-2		Wet....	Warm, 68.	18,650	4,940	3,180	1,027	22.5
	G-3	Air-dried in room.....	Dry.....	Frozen, 18.	27,630	7,380	4,000	1,189	8.3
	G-4	....do..............	Dry.....	Warm, 68.	27,950	7,450	5,600	1,035	7.9
Chestnut..	H-1	Thoroughly soaked, chopped out of solid ice.	Wet....	Frozen, 16.	9,015	2,250	1,750	604	(83.0)
	J-1		Wet....	....do....	9,800	2,460	1,880	592	83.0
	H-2	....do..............	Wet....	Warm, 45.	8,335	2,080	1,500	496	88.0
	J-2	....do..............	Wet....	....do....	9,245	2,320	1,760	361	92.0
	K-1	....do..............	Wet....	Frozen, 7.	17,590	4,340	3,700	787	(60.0)
	K-2	....do..............	Wet....	Warm, 68.	12,070	3,000	2,230	714	60.1
	L-1	Partly dry, wet spot in middle.	Partly..	Frozen, 7.	14,650	3,670	2,510	849	52.6
	L-2	....do..............	Partly..	Warm, 68.	12,360	3,090	2,500	642	50.4

Other tests of similar kind made under the direction of Mr. H. D. Hartley at the laboratory at the Louisiana Purchase Exposition upon green loblolly pine show similar results. Five series of two consecutive blocks each were tested in end compression, one set being exposed over night to a temperature of from 15° to 0° F. and the other kept warm.

Following is a summary of these tests:

TABLE 42.—*Other tests of the increase in strength produced by freezing temperatures.*

[Each value is the average of 5 tests.]

Condition at test.	Temperature during test.	Total load.	Moisture.
	° F.	*Pounds.*	*Per cent.*
Green warm..	60	4,673	50.0
Green frozen..	15	5,806	38.9

7. EFFECT OF SOAKING IN LIQUIDS OTHER THAN WATER.

To determine the comparative effect upon the strength of soaking in water with that of soaking in other liquids, 36 small compression tests were made upon air-dried material which was thoroughly soaked in water, spirits of turpentine, and kerosene for forty-three days. The results are given below.

TABLE 43.—*Comparative effect upon the compressive strength of soaking in various liquids.*

[Size of compression pieces ¾ by ¾ by 1½ inches. Each value is the average of three tests.]

Liquid.	Total load.		
	Longleaf pine.	Spruce.	Chestnut.
	Pounds.	*Pounds.*	*Pounds.*
Tested air-dry..	5,177	3,793	3,168
Water..	2,625	1,467	1,563
Spirits of turpentine..	3,940	2,677	2,330
Kerosene..	4,962	4,095	3,088

It is remarkable to observe that the kerosene seems to have no significant weakening effect.

Similar tests made at the Louisiana Purchase Exposition show that soaking in creosote oil slightly decreases the strength but not nearly so much as soaking in water.

Five series, each of three consecutive blocks of green loblolly pine, were selected and allowed to thoroughly air-dry before beginning treatment. The pieces were tested in end compression, thus: No. 1, air-dry; No. 2, soaked in water six days; No. 3, soaked in creosote six days. Moisture disks one inch thick were cut from No. 1 and No. 2 at point of failure.

TABLE 44.—*Effect of soaking air-dry loblolly pine in creosote.*

Condition at test.	Length of soaking.	Total load.	Moisture.
	Days.	*Pounds.*	*Per cent.*
Air-dry	0	7,098	9.1
Soaked in water	6	3,097	71.5
Soaked in creosote	6	5,742	[a] 70.0

[a] Liquid content, approximate.

Tests for the determination of other problems in regard to drying, soaking, steaming, etc., are under way at the present writing.

8. NOTES ON THE DISTRIBUTION OF MOISTURE IN LARGE BEAMS.

Large sticks are exceedingly slow in drying, a beam 12 by 12 inches in section and 16 feet long requiring some two years' drying in the air before it will have scarcely reached even the fiber-saturation point (25 per cent) in the interior.

Numerous experiments carried on by Mr. H. S. Betts, at the Washington, D. C., laboratory, upon loblolly and longleaf pine sticks of large sizes establish the following conlusions:

(1) The drying-out process takes place almost wholly through the faces of the beam and not longitudinally, except near the ends.

(2) The rate of evaporation through a surface is proportional to the rate of growth or density of the wood near the surface, being most rapid in the case of sapwood.

(3) If the whole stick is made up of heartwood or the proportion of sapwood is uniform throughout, the longitudinal distribution of moisture is very regular. If the proportion of sapwood is not uniform, on the other hand, the portion containing the most sap is the most susceptible to moisture influences; i. e., it will dry or will absorb moisture the most rapidly.

The average of two cross sections of longleaf pine sticks, 12 by 12 inches and 8 by 16 inches and 16 feet long, which were air-dried for two years, showed an average moisture content in the outer portion, cut half way from surface to center, of 17.7 per cent, while the inner part contained 25.7 per cent.

From this it is quite evident that where timber of structural sizes is used, the strength ordinarily reckoned upon should not be greater than that of the green condition.[a]

9. SUMMARY OF TESTS MADE AT WASHINGTON, D. C.

A summary of other tests made at Washington, D. C., upon large sticks of loblolly and longleaf pine, and minor sizes cut therefrom and tested at three moisture conditions, is given in Tables 45 and 46, with the comparative ratios. The variation in moisture in the tests averaged is too great to derive a correct moisture-strength curve, but the figures are of interest in confirming the results of the present investigation, and also in showing a comparison of the small 2 by 2 inch sizes in the wet and in the partially dried conditions.

[a] For further discussion see Circular No. 32 of the Bureau of Forestry.

TABLE 45.—*Summary of averages for tests on loblolly pine and longleaf pine.*

Where collected.	Material.	Size.	No. of tests.	Moisture.	Bending. Modulus of rupture, R.	Bending. Stress at elastic limit, f.	Bending. Modulus of elasticity, E.	Compression. Crushing strength, C.	Compression. Elastic limit, F.	Compression. Modulus of elasticity, Ec.	Specific gravity, G.	Rings per inch.	Sapwood.	Condition.
				Per cent.	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 pounds.*	*Lbs. per sq. inch.*	*Lbs. per sq. inch.*	*1,000 pounds.*			*Per cent.*	
North Carolina	Loblolly	8 x 14″	20	37.2	6,175	3,610	1,477				0.50	5.5	59	Air dry.
		4 x 8″	22	56.1	7,010	3,230	1,320	3,556	2,405	684	.47	4.8	66	Soaked.
		4 x 8″	21	26.4	7,790	3,810	1,432	4,310	3,095	875	.49	5.5	47	Air dry.
		2 x 2″	21	67.8	8,280	4,225	1,515	3,720			.48	5.1	62	Soaked.
		2 x 2″	14	17.8	10,300	5,830	1,600	6,550			.56	6.1	57	Air dry.
		2 x 2″	23	3.2	12,600	9,600	1,800	9,810			.51	5.4	52	Kiln dry.
Philadelphia	do	6 x 7″ 10 x 16″	15	20.8	5,750	3,050	1,405				.48	4.8	34	Air dry.
		6 x 7″ 6 x 16″	23	30.7	5,030	2,845	1,267				.49	5.0	38	Damp.
		4 x 12″ 8 x 16″	11	55.4	5,200	2,600	1,415				.50	6.3	29	Soaked.
Virginia	Rapid-growth loblolly	2 x 2″	23	73.7	7,491	3,987	1,369	3,402			.52	5.6	30	Soaked.
		2 x 2″	24	17.6	9,441	5,122	1,487	5,030			.51	5.9	33	Air dry.
		2 x 2″	23	1.7	13,170	10,500	1,809	10,270			.51	5.8	40	Kiln dry.
		8 x 8″	17	64.0	3,490	1,935	744	2,060	1,510	358	.43	3.0	68	Green.
		8 x 8″	13	23.3	4,990	3,140	1,160	2,900	2,170	528	.46	4.8	43	Air dry.
		2 x 2″	9	112.8	3,900	1,750	638	2,010			.40	3.1		Soaked.
		2 x2″	11	18.7	6,830	3,910	850	4,210			.44	4.0		Air dry.
		2 x 2″	11	5.6	10,200	5,900	1,205	7,280			.44	3.8		Kiln dry.
Do	Slow-growth loblolly	4 x 8″	12	46.3	5,080	2,070	1,184	2,780	1,770	455	.47	6.5	31	Soaked.
		4 x 8″	8	19.4	6,190	3,380	1,200	4,020	2,740	607	.47	8.1	32	Air dry.
		2 x 2″	9	47.6	6,820	3,200	1,100	3,180			.48	5.9		Soaked.
		2 x 2″	5	14.5	9,730	4,200	1,179	5,607			.53	6.3		Air dry.
		2 x 2″	7	2.8	11,800	8,370	1,510	10,600			.49	6.9		Kiln dry.
Philadelphia	Longleaf	6 x 8″ 10-16″	22	25.0	7,160	3,800	1,560				.58	13.7	6	Air dry and soaked.
		2 x 2″	15	33.9	9,070	4,950	1,540	4,100			.60	14.1	0	Soaked.
		2 x 2″	17	15.9	11,520	6,750	1,750	6,240			.56	13.9	0	Air dry.
		2 x 2″	14	3.4	18,450	13,350	2,270	13,300			.63	14.9	0	Kiln dry.

TABLE 46.—*Results of tests on loblolly pine reduced to uniform specific gravity of 0.50, and their ratios to the soaked condition.*

[Minor tests on 2" x 2" sizes, span 30".]

Where collected.	Material.	No. of tests.	Moisture.	Modulus of rupture, R.	Ratio.	Stress at elastic limit, f.	Ratio.	Modulus of elasticity, E.	Ratio.	Crushing strength, C.	Ratio.	Rings per inch.	Sapwood.	Condition.
			Per cent.	*Lbs. per sq. inch.*		*Lbs. per sq. inch.*		*1,000 pounds.*		*Lbs. per sq. inch.*			*Per cent.*	
North Carolina	Loblolly pine	21	67.8	8,630	1.00	4,400	1.00	1,578	1.00	3,870	1.00	5.1	62.00	Soaked.
		14	17.8	9,200	1.06	5,200	1.18	1,430	.91	5,850	1.51	6.1	57.00	Air dry.
		23	3.2	12,350	1.43	9,420	2.14	17,650	1.12	9,620	2.49	5.4	52.00	Kiln dry.
Philadelphia	do	23	73.7	7,200	1.00	3,830	1.00	1,315	1.00	3,270	1.00	5.6	30.00	Soaked.
		24	17.6	9,260	1.28	5,020	1.31	1,455	1.11	4,930	1.51	5.9	33.00	Air dry.
		23	1.7	12,900	1.79	10,290	2.69	1,772	1.35	10,070	2.04	5.8	40.00	Kiln dry.
Virginia	Rapid-growth loblolly	9	112.8	4,870	1.00	2,190	1.00	798	1.00	....	....	3.1	....	Soaked.
		11	18.7	7,760	1.59	4,440	2.03	966	1.21	....	....	4.0	....	Air dry.
		11	5.6	11,580	2.38	6,700	3.06	1,370	1.72	....	....	3.8	....	Kiln dry.
Do	Slow-growth loblolly	9	47.6	7,110	1.00	3,330	1.00	1,145	1.00	3,310	1.00	5.9	....	Soaked.
		5	14.5	9,180	1.29	3,960	1.18	1,111	.97	5,290	1.60	6.3	....	Air dry.
		7	2.8	12,030	1.69	8,550	2.57	1,540	1.34	10,810	3.27	6.9	....	Kiln dry.
LONGLEAF PINE—REDUCED TO SPECIFIC GRAVITY OF 0.60.														
Philadelphia	Longleaf pine	15	33.9	9,070	1.00	4,950	1.00	1,540	1.00	4,100	1.00	14.1	0	Soaked.
		17	15.9	12,330	1.36	7,230	1.46	1,863	1.21	6,680	1.63	13.9	0	Air dry.
		14	3.4	17,580	1.94	12,700	2.57	2,160	1.40	12,660	3.09	14.9	0	Kiln dry.

10. Volatile Oil Determinations.

In addition to the disks cut from the test specimens for determining the moisture content, sections 3 inches in length were taken from a number of the specimens out of each series in the case of the longleaf pine compression tests, from which to determine the amount of volatile oil present. The oil was extracted by distillation in the following manner:

The section was first reduced to shavings in a machine having a rotating circular plate 2 feet in diameter, with four knives set in the face radially and like the knife of a hand plane, against which the block of wood is pressed by an automatic feeding device. The shavings thus produced are suitably collected and are placed in a retort, which consists of a steam-jacketed brass cylinder, 3 feet long and 3 inches in diameter inside. The ends are closed by two screw caps, into each of which is inserted a small brass tube for passing steam through the retort. The steam is generated in an ordinary gallon flask, then passed through the shavings in the cylinder at atmospheric pressure, then through a straight glass tube with a cold-water jacket to condense the distillate, which then drips into a ½-gallon flask through a glass tube in the cork.

Excessive condensation within the retort was prevented by passing live steam through the jacket and by a Bunsen burner beneath the cylinder. As a little condensation still occurred within, the steam was cut off from the inside about an hour before the completion of the test, the heat in the jacket being continued, thus allowing the condensation to reëvaporate.

About 75 to 100 grams of shavings (dry weight) were used for each test, and about 1,500 c. c. of distillate was collected in the flask, the distilling process requiring about five hours. Experiment showed that no appreciable amount of oil distilled over after this period. The oil, being emulsified with the water, gives the latter a milky appearance and does not completely separate therefrom upon standing. To effect a separation the water was saturated with common salt, NaCl (about 2 parts of salt to 7 parts water, by weight). This solution was shaken up, corked, and allowed to stand overnight. About 100 to 175 c. c. of sulphuric ether, according to the amount of oil present, was then added, and the whole was thoroughly shaken up. After standing for half an hour it was again shaken up and allowed to stand at least ten minutes. The scum which collected from the dirt in the salt or the water was carefully removed, and the salt solution decanted from beneath by a siphon until but very little remained in the flask, with the clear ether solution on top. This remainder was poured into a burette with a Geissler stopcock in the bottom, containing a few cubic centimeters of clean water, and allowed to settle, and the rest of the salt solution was then entirely drawn off, leaving only the ether solution in the burette.

It was found by experiment that not enough oil remained in the decanted salt solution to be taken into account, and therefore repeating the entire extraction was dispensed with.

An experiment was made to determine the amount of ether which would be absorbed by clear water and by water saturated with salt, and it was found that the clear water dissolved 9.8 per cent by volume of ether, whereas the saturated salt solution dissolved only 1.6 per cent of its volume. Hence an additional reason for saturating the distillate with salt.

The clear ether solution of oil was next drawn from the burette into a beaker containing a small amount of dried Na_2SO_4 in the bottom. Any scum or dirt adheres to the sides of the burette and remains behind. The purpose of having the Na_2SO_4 in the beaker is to free the ether from any trace of water. Ether does not dissolve any NaCl nor Na_2SO_4. $CaCl_2$ does not serve the purpose, as it is somewhat soluble in the ether.

The solution was next poured off into another clean beaker and the oil separated from the ether by evaporating the latter in a hood in a dish of warm water, kept warm by a simple steam coil of rubber tubing, the steam being supplied from a generating flask. It can not be heated directly by a burner on account of the inflammability of the ether fumes. At first it matters not how hot the water bath is, since the ether can not be heated above its boiling point, which is much lower than that of the oil; but as the solution becomes more concentrated, the boiling point rises, and care must be taken not to overheat, since the

oil would then be evaporated also. The solution should not be heated above 35° C., the boiling point of the ether.

When the ether had all been evaporated, the remaining yellowish oil was weighed directly in the beaker on a chemical balance to milligrams. This weighing should be done at the critical point when the odor of ether can no longer be detected from the beaker, since the oil itself evaporates fairly rapidly even at the temperature of the room. While it was the aim to make the weighings at this particular point, it frequently happened that some time elapsed before it was discovered that this point had been reached, as the attention of the operator had to be given to other things during the slow process of evaporation. The loss in half an hour or so is not, however, of material consequence, when expressing the result in per cent of the dry weight of wood.[a]

It seems probable that the method of extraction by ether does not give as large a percentage of oil as there actually is in the specimen, since some of the oil is necessarily evaporated, together with the ether, although the temperature is far below the boiling point of the oil. It gives, however, the best result which can be obtained without a much more complicated process. A series of tests made synthetically, starting with a known quantity of crude turpentine, showed an average loss of about 40 per cent. The shavings were taken from the retort, placed in a porous basket, dried in an air bath at 100° C., and then weighed. The weight of oil multiplied by 100, divided by the dry weight of the shavings, gives the percentage of oil present, based upon the dry weight of the wood.

It was now possible to correct the moisture per cent by subtracting the per cent of oil. With the exception of an abnormally resinous series, which contained 7 per cent of oil, the amount was so small as to make any correction in the moisture determination superfluous.

The results of the oil determinations show an average (excluding the extremely resinous series, No. VII) of 0.47 per cent, green and soaked. Assuming a loss of 40 per cent in the extracting process, this would be 0.78 per cent.

The results, as obtained in the foregoing tests for volatile oil, are given in the table below:

TABLE 47.—*Per cent of volatile oil in longleaf pine of various degrees of moisture.*

	Soaked.	Green.	Moist.	Partly dry.	Dry.	Kiln-dry.	Oven-dry.	Resoaked.
Series I	0.17		0.11	0.10	0.16	0.11		
II		0.21	0.22	0.19	0.23			
III	0.25	0.30	0.26					
IV	1.10	1.12			1.30			
V	0.56			0.27	0.27	L.	0.42	
VI		0.48	0.34		0.40	0.44	0.50	0.38
VII	5.5	7.1	5.0		5.4		3.0	

[a] Regarding the rate of evaporation at the temperature of the room, the following instance was recorded:

	Approximate diameter of beakers.	
	2½ inches.	3½ inches.
Total weight of oil in beakers	0.325 gram.	0.698 gram.
Average rate of evaporation per hour	.021 gram.	0.045 gram.
Amount of total weight evaporated per hour	6.5 per cent.	6.4 per cent.

APPENDIX B.

Microscopic Study of the Fracture.

The great difference in the behavior of different kinds of wood when under stress is due chiefly to their cellular structure. A microscopic examination of the first beginnings of failure shows some interesting results. It is a mistaken idea to suppose that the fibers slip upon themselves; on the contrary, the adjacent walls invariably rupture rather than slip apart.

A study of failure in compression parallel to grain reveals two distinct ways in which this occurs—either by a gradual bending of all the fibers, or else by a buckling of the cell walls themselves, followed finally by a bending over of the fibers. This will be most clearly understood from the illustrations, which were made by the author from the microscope.

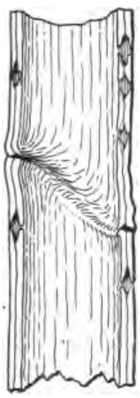

Fig. 21.—Tangential section, of a single fiber (tracheid) of dry red spruce, showing first indication of failure under compression parallel to grain.

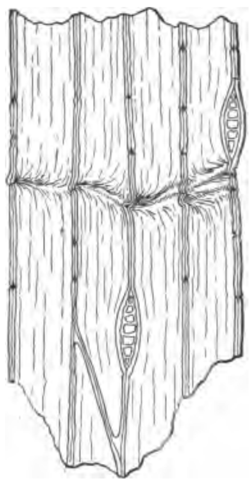

Fig. 22.—Beginning of failure under compression parallel to grain, showing buckling of cell walls. Dry red spruce.

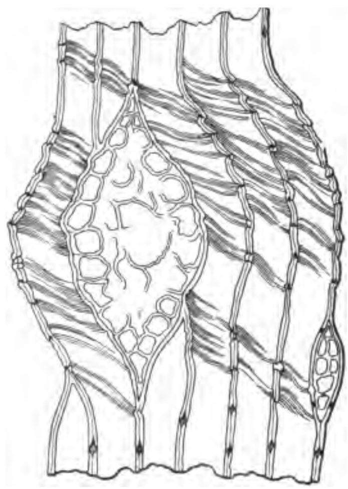

Fig. 23.—Failure under compression parallel to grain further progressed. Dry red spruce.

Fig. 21 shows a tangential section of a single fiber (tracheid) of dry red spruce, highly magnified, in which failure by compression is just starting. It will be seen that a ridge or buckle of the cell wall has formed diagonally around the fiber, the failure starting apparently with two "bordered pits" which are on the radial walls of the cells.

These "bordered pits," which are small lentil-shaped spaces in the walls of the cells, opening into the cell cavities by two small round holes (see fig. 24), occur in all fibers of the conifers, and in some of the fibers of the hardwoods. It seems very probable that these bordered pits are the cause of this peculiar kind of failure, which occur in longleaf pine as well as in spruce, but was not found in chestnut or ash.

Figs. 22 and 23 show progressive stages of the failure in dry red spruce, figure 23 showing also the spreading apart of the fibers due to a large medullary ray.

Fig. 24 is a radial section of the same kind of material at an early stage of failure under compression, corresponding to the condition shown in figure 23. Here may be seen the bordered pits referred to, some of them having been crushed as the walls buckled.

Fig. 25 illustrates the other kind of failure, by bending without buckling. This was taken from a piece of dry chestnut. Dry ash showed a similar result. All wet or green woods fail in this way, even spruce and pine.

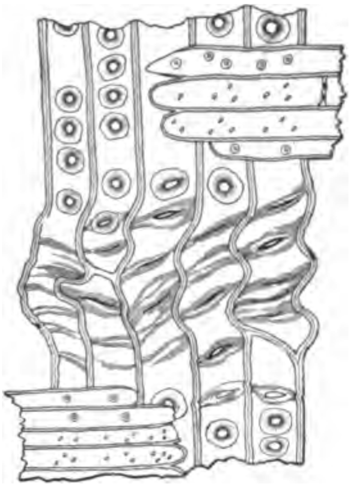

FIG. 24.—Radial section of dry red spruce, showing failure under compression parallel to grain.

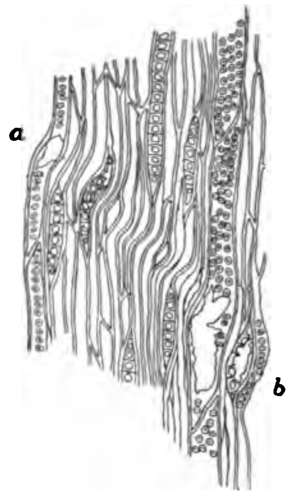

FIG. 25.—Tangential section of dry chestnut, showing beginning of failure by compression parallel to grain.

From the foregoing facts the inference naturally follows that all species of wood which, when dry, show the first indication of failure under compression by a buckling of the cell walls without bending of the fibers, would be rigid, brittle, difficult to bend without breaking, and would increase rapidly in strength with dryness. On the other hand, species which, when dry, show a bending of the fibers without buckling of the walls would be expected to exhibit the opposite qualities. Here then is a means by the use of the microscope of predicting some of the strength qualities of species of wood. The inference just drawn is true of the woods examined, and may be taken provisionally as a general law.

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